INDUCED TECHNOLOGICAL CHANGE

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IN

UNITED STATES MANUFACTURING INDUSTRIES

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By

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TO

MY MOTHER, AND THE MEMORY

OF MY GRANDMOTHER

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ABSTRACT

Recently, technological change has received increasing attention from researchers. One of the many questions addressed has been concerned with the forces that govern the rate of inventive activity and hence technological change. Two distinct strands of argument have appeared in historical succession. Broadly speaking, these can be distinguished as pertaining to either the supply of or demand for inventive activity as the major determinant of technological change.

First, following the historical progression, was the argument that the supply of inventive activity (the development of basic science and occasional appearance of inventive genius) was the crucial factor in determining its rate, in which case inventive activity was treated as exogenous to the economic system.

Recently, however, the argument seems to have shifted in favour of the primacy of the demand for inventive activity. The proponents of this argument suggest that inventive activity is governed by market forces, which would make it an endogenously determined variable. Demand for inventive activity is a derived demand. Although, in this respect, the role of final product

demand has been stressed, there is yet no consensus as to what other variables may affect the derived demand for inventive activity. Which of the two above mentioned positions accurately represents the generation of inventive activity has implications for policy designed to influence technological change.

The present study is an attempt to explore the role of supply and demand forces in determining the rate of inventive activity. Empirical investigation, based on a simple model of induced technological change, is carried out for 11 manufacturing industries in the United States.

The evidence indicates that demand for inventive activity is a significant determinant of inventive activity in the industries studied. The demand side variables (output, relative factor prices, and the state of technology) performed fairly well in explaining R&D expenditures (as an index of inventive activity).

Unfortunately, the evidence about the effect of the supply of inventive activity (represented by the state of knowledge in the respective industries) remains inconclusive. However, the results in conjunction with the individual industry characteristics indicate that the effect of supply side of inventive activity is much more complex than assumed in the present study. This leads to certain suggestions for further research which will take the supply side of inventive activity into consideration more effectively.

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CHAPTER ONE

INTRODUCTION

Inventive or innovative activity is not a new topic in economics though it has become topical in recent years. It goes back to Ricardo (1821), Mill (1848) and is, therefore, as old as the discipline of economics itself. Schumpeter(1911) was responsible for bringing innovative activity to the forefront. In his framework it served as the major vehicle for economic change and growth. In spite of Schumpeter's emphasis, the subject did not receive the attention it deserved from the economics profession until 25 years ago, when it became quite clear that inventive activity and technological change have had much more profound effects on economic growth than has hitherto been understood. This fact has generated a considerable enthusiasm, and the subject of inventive activity has become a matter of active debate. One of the pertinent questions in this debate has been: Why does inventive activity take place and what factors govern its magnitude?

Although, of late, this question has been pursued with a renewed vigour, nevertheless, it is not a new question. It has been under discussion for a fairly long period of time. In addition to economists, this question has occupied attention of applied technologists, sociologists, and the historians.[1] Different theories have been put forth to explain inventive activity. Professor Usher (1954) has summed up these theories under two general approaches to the problem: The transcendentalist and the mechanistic. He also provides an alternative of his own which he calls the cumulative synthesis approach.

According to the transcendentalist approach invention is the work of an occasional genius. Viewed this way inventions are more or less accidental in nature in so far as a genius perceives the problem that needs to be overcome. Usher, however, argues that the historical evidence does not support this theory. The act of insight required for invention has not been as rare a phenomenon as the transcendentalists would assume. Besides,

> "The act of insight which results in the perception of a new relationship requires a highly specific conditioning of the mind within the framework of the problem that is to be solved".[2]

Sharply in contrast to the transcendentalist approach is the mechanistic process theory as proposed by Chicago sociologists.[3] Inventions are the result of a chain of individual efforts over a long period of time. Gilfillan (1935, p. 10) emphasizes that "there is no indication that any individual's genius has been necessary to any invention that has any importance". In a more familiar framework whereas the transcendentalists stress the importance of the supply side of inventive activity, the proponents of the mechanistic process theory regard the demand side of inventive activity as more significant.

Usher's alternative theory, which he calls the cumulative synthesis approach, is appropriately a synthesis of the transcendentalist and the mechanistic approaches. In his *"A History of Mechanical Inventions"* (1954, p. 61) he points out that;

> "Insight is not a rare, unusual phenomenon as presumed by the transcendentalist; nor is it a relatively simple response to need that can be assumed to occur without resistance and delay".

The cumulative synthesis theory suggests that the major inventions are the result of a cumulative synthesis of past minor inventions. Both major and minor inventions do require an individual act of insight.[4] In Usher's theory both supply of and demand for inventive activity play an important role in determining the extent of inventive activity.

Until 25 years ago, economists generally thought that the supply of inventive activity was the determinant factor as far as the rate of inventive activity and technological change was concerned; and since the supply of inventive activity was considered governed by non-economic forces, not much attention was devoted to it. The subject of inventive activity occupied only a peripheral position in the discipline of economics. Since that time, however, the situation has changed drastically. Inventive activity is no longer regarded as a peripheral subject in economics. It has retained a central position in economic thought. After the significance of technological change in economic growth became known, detailed studies of inventive activity were called for irrespective of whether supply or demand forces played a more important role in determining its magnitude.

The detailed study of inventive activity led to a revision of ideas about the roles of demand and supply forces. In contrast to received thinking, economists such as Carter and Williams (1957), Nelson (1959), Brozen (1960), Sutherland (1959), and especially Schmookler (1966) proposed that the demand for inventive activity was much more important in determining the rate of inventive activity than had so far been conceded. Before attempting to verify the roles of different forces in this respect the usual definitional and measurement problems had to be faced. The measurement of inventive activity poses a familiar but difficult problem.

In his *"Inventive Activity: Problems of Definition and Measurement"*, Professor Simon Kuznets has elaborated that,[5]

> "an invention has a technical and an economic side; and, of course, it has a past and a future. The combination of these two sets of aspects gives us four views of the magnitude of an invention: (1) the technical problem overcome - a view of the technical past; (2) the technical potential, ie., the effect of the invention on further technical changes and the progress of technology in general - a view of the technical future; (3) the economic cost, ie., the resources consumed or foregone in the "production" of the invention - a view of the economic past; and (4) the economic potential, ie., the contribution of the invention to cost reduction or to the production of new goods in the economy - a view of the economic future. ... As an economist I would be willing to settle for meaningful quantities under (3) and (4). But knowing that no easy answers are available, I feel compelled to retain (1) and (2), for whatever help the examination of the technical problems and potentials of an invention may give us in considering its economic cost and contribution".

No wonder then that researchers have concentrated their efforts on (3) and (4); and more on (3) than (4). This is clear when Sanders wrote that "the measurement of inventive activity by way of inventive input is perhaps the most direct and the most defensible logically".[6] The early studies, in the absence of data on inventive inputs (R&D expenditures),[7] used the available data on number of patents as an index of inventive activity. Patents are the output of inventive activity and would seem to correspond to the second of Kuznet's measures. The difficulties in this respect as referred to by Kuznet's are highlighted by Sanders when he says,

> "I have tried to show there is no sound basis to assume that decade after decade the quality of patents has remained constant. Furthermore, there is no basis for assuming that inventive activity leading to patents has remained constant in relation to inventive activity in general, including that which gives rise to unpatentable inventions and those not patented for one reason or another".[8]

The availability of reasonably sufficient data on R&D expenditures in recent years has encouraged researchers to pursue the question raised in the beginning of this introduction: What factors determine the extent of R&D expenditures and, therefore, the rate of inventive activity. However, the studies conducted to date do not provide sufficient evidence to support a general concensus on the subject or guidelines for policy in the area of R&D activity.

The researchers exploring the area have stressed the importance of the demand side of inventive activity. More specifically, according to Schmookler, it is the demand for the final product (for example in an industry) that determines the demand for inventive activity.[9]

There, however, may be other variables that influence the demand for inventive activity, e.g., Hicks (1932) pointed out that relative factor price changes may also affect the inventive activity.

Commenting on the effect of the supply side of inventive activity Schmookler proposed that the supply side of inventive activity is important only in the sense that it determines what sectors (industries) the inventions are produced by.[10] This suggests that it is necessary that a study exploring the effect of different variables on the rate of inventive activity take individual industry characteristics into account.

The present study is an attempt in that direction. It sets out to explore the effect of different variables on inventive activity, as measured by R&D expenditures, in different industries in the United States with the help of a model of induced technological change. It is hoped that it will shed some light on the significance of different forces (supply and demand) in the determination of inventive activity.

The next chapter is devoted to a brief review of the literature on the subject. In Chapter Three a simple model of induced technological change is developed in which both demand and supply variables are included. Chapter Four discusses the data, its sources, limitations, and the specification of different variables used in the empirical application. Chapters Five and Six are devoted to the presentation and discussion of the results. Chapter Seven concludes the study with some suggestions for further research.

CHAPTER ONE: FOOTNOTES

1
Ruttan, V. *"Usher and Schumpeter on Invention, Innovation and Technological Change"*, Quarterly Journal of Economics, Nov., 1959, p. 600.

2
Ibid., p. 603.

3
See Gilfillian, S.C. *"The Sociology of Invention"*, Follett Publ., 1935.

4
Usher outlines four steps required for individual inventions: 1) perception of the problem; 2) setting the stage; 3) the act of insight, and 4) critical revision (1954).

5
In: R.R. Nelson (ed.) *"The Rate and Direction of Inventive Activity: Economic and Social Factors"*, Princeton University Press, 1962, pp. 24-25.

6
In: R.R. Nelson (ed.) *"The Rate and Direction of Inventive Activity: Economic and Social Factors"*, Princeton University Press, 1962, p. 75. Saunders also notes that

> "the second approach, which also seems rational, at least in the abstract, is to measure inventiveness or inventive activity in terms of its outcome, technological advance. But the measurement of technological advance per se presents many practical problems. Therefore, it is difficult for me to see, for instance, how one can use the approach advocated by Hart to measure inventiveness. If the measurement of output proves a useful approach, it would seem to me it would have to be in terms of increased labor productivity as a result of inventiveness. But as we indicated, this would not be merely measuring inventiveness but also the speed of its adoption and the extent of its use. In other words, this would mean the abandonment of the conceptual purism of the rate of invention per se, separate and distinct from innovation and the dissemination of its use (which some call imitation)".

7
The U.S. National Science Foundation started compiling data on R&D expenditures in the mid 1950's.

8 *In:* R.R. Nelson (ed.) *"The Rate and Direction of Inventive Activity: Economic and Social Factors"*, Princeton University Press, 1962, p. 76. He, however, notes that

> "even though I question the utility of the patents count as an index of inventiveness, or inventive activity, I think that patents as verified inventive acts present a unique resource for study and understanding of the inventive process."

9 Schmookler used the number of patents as an index of inventive activity (for more details, see Chapter Two). The question of inventive activity has another complicated dimension which is particularly relevant to this argument. Inventive activity increases the productivity of labour and consequently income and demand in general. And, according to the present argument, an increase in demand would lead to an increase in inventive activity. There is, therefore, a circularity in the argument and it would seem that inventive activity reinforces itself.

Minasian has shown in his *"The Economics of Research and Development"* (printed in *"The Rate and Direction of Inventive Activity: Economic and Social Factors")* that R&D expenditures explain the rate of growth of productivity in the industries he studied. This issue was addressed by Professor Mathews (see his *"The Contribution of Science and Technology to Economic Development"*, in B.R. Williams (ed.) *"Science and Technology in Economic Growth"*, International Economic Association, 1973) when he wrote

> "Eminence in science seems to be rather more closely related to the level of a country's income per head; but here the direction of causation is a major problem, since a rich country is able to devote more resources to science than a poor one, just as it can to other fields of human endeavour. A rather better case can be made for the view that a country's rate of economic growth depends on its success in using scientific and technological advances for commercial purposes."

For a developing country it would be an interesting question to ask whether it should give priority to its science policy or try to raise its income level per head.

10 See Chapter Two for more details.

CHAPTER TWO

INDUCED TECHNOLOGICAL CHANGE: A BRIEF REVIEW OF THE LITERATURE

2.1. Technological Change

Treatment of technological change as an endogenous variable is a very recent phenomenon. In a glaring contrast to the writings on the subject as late as the early sixties, almost all the recent work has a tendency to assume that technological change is endogenous to the economic system. A considerable credit for this reversal of trend goes to Professor Schmookler's writings, which were part of a general resurgence of interest in the subject of technological change after the publication of a number of studies on the productivity of factor-inputs, and efficiency in general.[1]

In essence, these studies attributed most of the productivity growth in the U.S. to technological change rather than physical inputs, ie., labour and capital. This occasioned a considerable surprise and started a process of reorientation in thinking towards the factors that have traditionally been considered crucial for economic growth.

Technological change emerged as the most important variable in determining the rate of economic growth. This finding was a little unpleasant for the economics profession since technological change was considered outside its domain. However, once it became known that economic growth could not be adequately explained by mere physical inputs, that rather it had to be explained and understood in terms of learning to use inputs more productively, it automatically made technological change the focal point of the studies on productivity and economic growth.

Mansfield defines technological change as

> "the advance of technology[2], such advance often taking the form of new methods of producing existing products, new designs which enable the production of products with important new characteristics, and new techniques of organization, marketing and management".[3]

How does technological change take place? An answer to this question amounts to classifying the hierarchy of activities involved in bringing about technological change. The following is typical of the sequence involved as given by Ames (1961, p. 369), where output of each stage feeds into the next: basic research, inventive work, development work, and innovation. The National Science Foundation (NSF) uses a similar framework: basic research, applied research, and development (see Sanow, 1959, p. 124). But NSF coverage seems narrower than Ames' because the NSF

> "...does not include quality control, routine product testing, market research, sales promotion, sales service, research in social sciences or psychology, or other nontechnical activities or technical services."

It is not easy to draw a concrete distinction between these activities especially between invention and development work since distinction between them is merely one of degree. Jewkes, Sawers, and Stillerman (1969, p. 25), who identified three sequential stages: science, invention, and development, did refer to this difficulty:

> "There can be no doubt that an over-rigid insistence upon definition would immediately bring all discussion of invention, and the part it plays in changes in ways of living, to a dead stop. The choice must be between discussing these matters with concepts that are necessarily somewhat vague and not discussing them at all."

It is in this spirit that we try to elaborate, though not in much greater detail , the stages as identified by them. There are a number of important differences between the first stage (i.e., science) and the other two:

(i) First of all, science is essentially "directed towards understanding", while the subsequent two activities are "directed towards use".

(ii) Secondly, while the magnitude of achievement in science can only be judged by other scientists trained in the field, the level of success in the later two is judged, ultimately, by the market place.

(iii) Thirdly, science, as a body of knowledge accumulated over time, in a very fundamental sense, reflects the supply side of inventive activity while the other two are primarily affected by, and thus represent, the demand for inventive activity.

Science is the social pool of knowledge accumulated over a long period of time which Schmookler (1966, p. 11) calls "society's intellectual heritage". Basic research draws on this intellectual heritage to develop hypotheses, theories, and research papers that could be called, following Ames (1961, p. 370), "new statements about the natural world". At a given period of time, science determines the set of possible inventions. Binswanger (1978, p. 100) names the outer boundary of this set as the "scientific frontier". For example, any invention in the microbial and to a great extent the biological world could not be made without the assistance of microscopy, and in a similar way the contemporary study of the atomic structure of giant molecules awaited the technique of x-ray crystallography. Thus supply side represents the binding constraint. It determines the domain of possible inventive activity.

Invention, on the other hand, needs the same kind of inputs as basic research in addition to the output of basic research to produce "a flow of prototypes of articles which have never been made before or processes that have never been used before" (Ames, 1961, p. 370).[4]

> "We can define 'invention' simply as a prescription for a producible product or operable process so new as not to have been 'obvious' to one skilled in the art at the time the idea was put forward, or we can add to the requirement of novelty the additional one of prospective utility" (Schmookler, 1966, p. 6; emphasis original).

Finally, development work is defined as utilization of the invention in conjunction with required personnel such as engineers, draftsmen, etc., to produce blueprints or prototypes of commercially viable products or plants with new characteristics of commercial value.

From invention to the final marketable product is the domain of 'development activity' that includes innovation and a whole host of minor improvements which have recently shown to be much more important than originally thought. Jewkes *et al.* credit Schmookler for the important observation that the accumulation of many small inventive advances often outweighs the effect of major invention (1969, p. 209).

Mansfield (1968, p. 18) also points out that:

> "In addition, the rate of technological change depends on the amount of effort devoted to making modest improvements that lean heavily on practical experience. Although there is often a tendency to focus attention on the major, spectacular inventions, it is by no means certain that technological change in many industries is due chiefly to these inventions, rather than to succession of minor improvements..."

Development thus represents a whole spectrum of activities where innovation may come in the end or may be followed by a chain of minor improvements to make the product commercially successful.

Research and Development is commonly considered as the source of technological change. What determines the level of Research and Development (R&D) expenditures and hence the rate of technological change is a question that we wish to consider in the present study. Before that, it is worth pointing out that Mansfield (1968) has shown the presence of a systematic relationship between R&D expenditures and the number of patents in an industry which is taken as an index of inventive activity by Schmookler (1966).

2.2. Factors Affecting the Rate of Technological Change[5]

2.2.1. Demand

Normally it was thought that technological change was governed by its own internal logic and thus was exogenous to the economic system. Put differently, it was the supply of technological change as regulated by the accumulation of knowledge over time that determined what inventions and hence innovations could be, and were made. This overwhelming emphasis on supply side forces rendered the question of technological change uninteresting for the economists. However, the postwar interest in the subject of growth and studies conducted thereafter resulted in some startling observations which the received theory failed to deal with adequately. For example, in view of a substantial part of productivity increase attributed to technological change, it was necessary to include technological change formally in the growth theory and to study its linkages with and effects on other economic variables more closely even if it was to be treated exogenous to the economic system.

Schmookler worked consistently on the subject throughout his lifetime.[6] Progression of his work slowly started revealing that technological change was influenced by economic variables. As more and more evidence became available, he grew more and more critical of treating technological change as an exogenous variable.[7] In his "*Technological Change and Economic Theory*" (1965, p. 335), he wrote;

> "Economic activity is concerned with the satisfaction of human wants. Technological progress permits those wants to be satisfied better than pre-existing knowledge did. While some inventions are made by accident, most of them are made on purpose. Since making them is neither easy nor costless that inventive resources tend to be allocated among alternative projects in accordance with anticipated profits is only to be expected. In short, in the main the production of new technology is itself an economic activity. It represents in essence the mobilization of society's creative energies to relieve the scarcities which existing resources and products cannot. Far from being an exogenous variable, it is one of the most interesting endogenous variables of them all."

Inventive activity and hence technological change is thus an economic activity which is affected by the same considerations as any other economic activity, namely its profitability. It is subject to the laws of supply and demand like any other economic activity.

Accordingly, Schmookler (1966, pp. 11-12) states:

> "Chance factors aside, joint determinants of invention are (a) the wants that inventions satisfy, and (b) the intellectual ingredients of which they are made. The inventor's problem arises in the world of work and play, rest and action, frustration and satisfaction, health and sickness, and so on. That world, together with his estimate of the difficulty of solving the problem, provides the basis for his judgment that the solution is worth seeking. On the other hand, in order to analyze the problem, to imagine possible solutions to it, to estimate their relative cost and difficulty, and to reduce one or more to practice, the inventor must use the science and technology bequeathed by the past. Thus, in a fundamental sense, both wants and accumulated knowledge are necessary to invention. Neither alone is sufficient. Without wants no problems would exist. Without knowledge they could not be solved."

Past knowledge determines the set of possible inventions whereas wants determine the set of desirable inventions. The set of inventions made at a particular moment is presumably an intersection of those two as Schmookler would say (1966, p. 12):

> "That we cannot invent all that we want is certain. That we invent all that we can seems improbable. Roughly speaking, we invent what we can, and, in some sense, want badly enough".

Though recognizing the importance of the supply-side of inventive activity he assigns it a passive role, whereas the demand-side, which determines the set of desired inventions, plays a dominant role in his framework.

Schmookler did not stop there. He argued that, in fact, his analysis also explains the pattern of inventive activity in different industries. He refuted the Kuznets-Salter explanation of the S-shaped pattern of industrial growth.[8] They had argued that as an industry grows, inventive potential is slowly exhausted which gives rise to S-shaped growth curve. In other words, the explanation for the S-shaped growth curve was to be found in decreasing returns to inventive activity itself. As an industry grows, further improvements in its technology become increasingly difficult. Thus the S-shaped growth curve reflects the constraints on the supply-side of inventive activity. It is the progressive increase in the cost of making an improvement in the technology that results in gradual tapering-off of growth of an industry. Consider the comparative-static case of a typical industry at a particular time whose long-run supply curve is given by S_1 in Figure 2.I.[9] D_1 represents its demand curve. Equilibrium level of output is Q_1. Exogenous technological change shifts the supply curve from S_1 to S_2 over time which means a lower price for the consumer and higher output, and presumably profits for the industry.[10] Successive shifts in the supply curve grow smaller and smaller as industry grows up to a certain point when the inventive potential of the industry is almost completely exhausted and the industry stops growing any further.

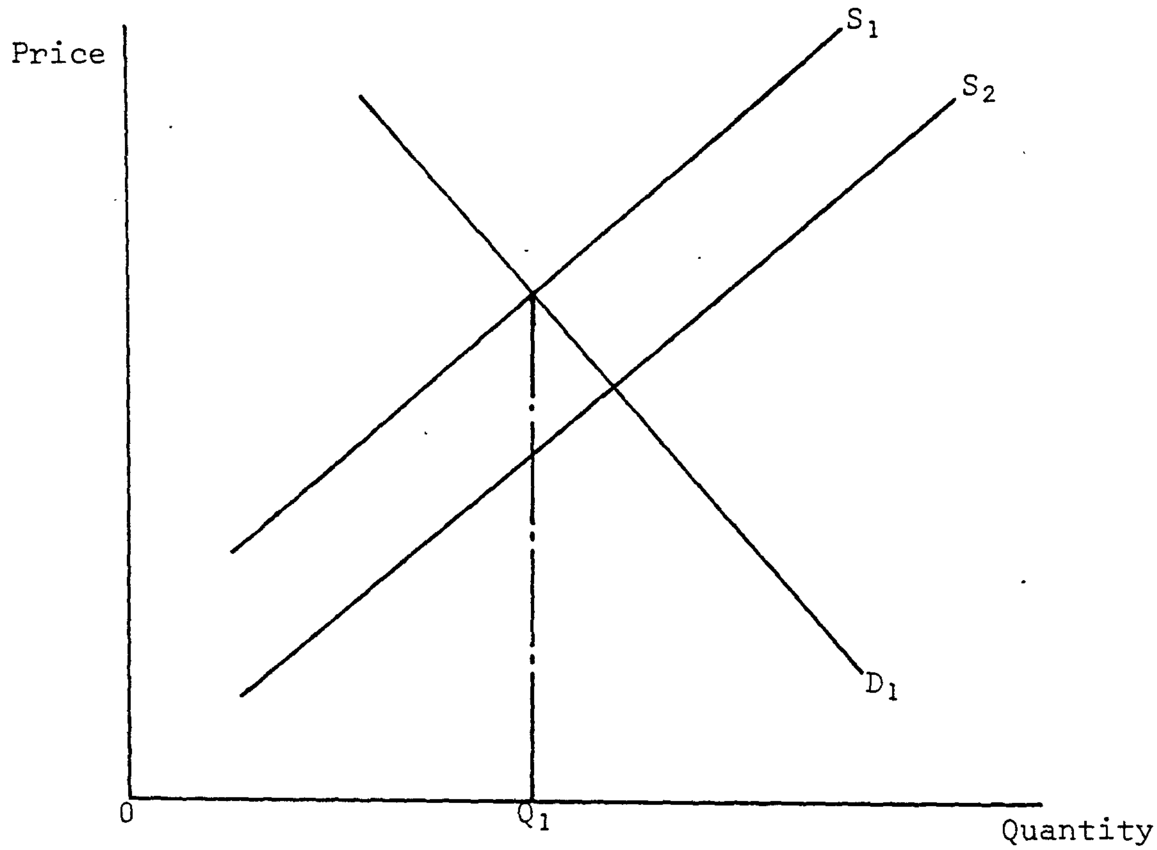

Figure 2.I.

Aggregate Demand and Supply in an Industry

Schmookler (1966, 1972) quite convincingly disagreed with the Kuznets-Salter explanation. Instead of supply, he proposed that explanation has to be sought in the demand for the product of the industry concerned:

> "The question we wish to consider, therefore, is whether the characteristic ultimate decline of invention in a field usually results from an increase in the <u>cost</u> of a given percentage increase in physical productivity or from a decrease in the value of such an increase in productivity. If the former, then the decline of invention in the field is to be explained by the operation of the principle of diminished

> returns in the production of knowledge in the field. If it is the latter, then the decline is to be explained by some aspect of the demand for the good in question, in the simplest case, by the principle of diminishing utility".

And he continues to conclude that:

> "...technical progress in an industry slows down ordinarily because it becomes less valuable and not because it becomes more costly...For it implies that the S-shaped growth curve which characterizes the output-path of individual industries usually reflect demand, not supply, conditions." (1966, pp. 90-97)

His empirical evidence suggests that shifts in the supply curves, to a large extent, were induced by those in the demand curves. It is the saturation of demand - in other words the decline in income and price-elasticities - that explains the phenomenon of inventions becoming less valuable as a typical industry expands.

Thus according to Schmookler technological change is primarily an economic activity which is directed towards areas of highest expected returns. It is subject to more or less the same laws that regulate any other economic activity. A particular improvement which increases the productivity of inputs by, for example, 10% will be more valuable in a larger than in a smaller industry. Consequently, inventive resources of the economy are allocated to different sectors of economy according to the level of economic activity in those sectors.

Schmookler's contention is much more strong than just that technological change is endogenous, in that he also tries to explain the pattern of inventive activity by the pattern of economic activity in general in an industry. It is easy to concede that technological change is endogenous but it is hard to prove that the pattern of inventive activity could be explained entirely by the demand side forces regardless of supply-responsiveness of technology and invention. This is precisely the focus of criticism against Schmookler's position.

The supply-side of inventive activity plays a role in so far as it determines the manner in which the demand for inventive activity is fulfilled. In other words, it determines which industries or branches of science and technology generate the inventions. For example, if it is easier to invent electrical machines than non-electrical machines, then the aggregate demand for new machinery would tend to induce more electrical than non-electrical machinery inventions. "In brief, inventors tend to select the most efficient means for achieving their ends, and at a given moment, some means are more efficient than others" (Schmookler, 1966; pp. 211). The reason for this, Schmookler suggests, is that

> "...mankind today possesses, and for some time has possessed, a <u>multi-purpose knowledge base</u>. We are, and evidently for some time have been, able to extend the technological frontier perceptibly at virtually all points" (1966, p. 210, original emphasis).

It is due to this versatility of man's enlarged inventory of scientific and technical skills, that demand-side forces retain their primacy. That the presence of demand leads to an effort on the part of inventors to satisfy it, though central to the endogeneity of technological change, does not necessarily explain the pattern and timing of inventive activity.[11] It may take a considerably longer period for some of the required inventions to come about as compared to some others. In this connection Professor Rosenberg points out that

> "The role of demand-side forces is of limited explanatory value unless one is capable of defining and identifying them independently of the evidence that the demand was satisfied" (1976, p. 268, emphasis original).

It is true that a number of very important categories of human wants have long remained unsatisfied or insufficiently catered to in spite of a well-established demand. This is particularly true in the area of medical science. Rosenberg argues quite forcefully with the cases of the development of bacteriology (which was crucial for the thrust of medical inventions in the twentieth century), the slow progress in the field of organic chemistry as compared to inorganic chemistry and the substitution of mineral fuel for wood in industrial activity (which took almost two hundred years to complete), that Schmookler's analysis remains deficient without a careful scrutiny of supply side variables.

It is the complexity of the technology upon which scientific research depends that has to be examined for an explanation.

> "...It is not surprising that the disciplines which were carried to the most advanced state in antiquity were astronomy, mathematics, mechanics and optics. These were each disciplines which could be carried far on the evidence of unassisted human observations, with little or no reliance upon complex instruments or experimental apparatus" (Rosenberg, 1976, p. 269).

A second, but related, objection has been raised against Schmookler's proposition that

> "A million dollars spent on one kind of good is likely to induce about as much invention as the same sum spent on any other good. Hence, doubling the amount spent on one kind of good is likely to double the inventive activity those expenditures induce" (1966, p. 172; emphasis original).

This suggests that the supply of inventions is perfectly elastic at a particular time and it is possible to get as many inventions as is desirable at a given price, in all industries. This, according to Rosenberg, is an unduly strong proposition which completely ignores the supply-side considerations. According to him:

> "As scientific knowledge grows, cost of successfully undertaking any given, science-based invention declines - from infinitely high, in the case of an invention which is totally unattainable within the present state of knowledge, down to progressively lower and lower levels" (1976, p. 278).

Thus the interesting and more relevant case is the less than perfectly elastic supply curve where both supply and demand sides interact to determine the amount of inventive activity undertaken. A similar view is expressed by Mansfield (1968, p. 18).

2.2.2. Relative Factor Prices

A second perspective on technological change is developed by the proponents of the theory of induced innovation. Whereas demand for the product plays the pivotal role in Schmookler analysis, relative factor prices[12] play the central role in the induced innovation hypothesis. Schmookler never dealt with the role of factor-prices in affecting the rate of technological change.[13] The reason is that his primary interest focussed on invention rather than innovation. While it is fruitful to keep a distinction between the two for analytical clarity, it is nonetheless true that both invention and innovation affect the rate of technological change.

Inventions are made with the ultimate aim of their commercial success and for that they have to pass through the stage of innovation. A substantial part of R&D expenditure is indeed devoted to development work and it has already been pointed out that it is very difficult to distinguish between different activities leading to technological change. Mansfield (1968, p. 50) has pointed out that "inventions can occur in the research phase or development phase of organized R&D activity."

Our analysis of inventive activity carries over to innovative activity. This is to be expected since innovative activity is guided more by market considerations. That innovations are demanded in response to a change in demand conditions (market size) is thus quite apparent from the discussions so far. On the other hand, innovations could also be demanded as a result of changing relative factor-prices. This is the subject of the induced innovation hypothesis.

The inspiration for the induced innovation hypothesis comes from Hicks (1932, pp. 124-125) where he stated:

> "The real reason for the predominance of labour-saving inventions is surely that which was hinted at in our discussion of substitution. A change in the relative prices of the factors of production is itself a SPUR to invention, and to invention of a PARTICULAR KIND - directed to economizing the use of a factor which has become relatively expensive. The general tendency to a more rapid increase of capital than labour which has marked European history during the last few centuries has naturally provided a stimulus to labour-saving invention".(emphasis mine)

Hicks made two assertions in this statement. First, relative factor-price changes lead to an increase in inventive activity, and second, they lead to inventions of a particular kind. This distinction has not, so far, been made in the literature building on the Hicksian position but it is important to make this distinction. Even Hayami and Ruttan (1971) and later Binswanger (1978) who are the main exponents of Hicksian position in its complete form fail to point this out. While endogeneity of technological change is suggested in the first, it is not necessary for the second assertion. Put differently, the first assertion proposes, in the present context, that relative factor-price change will affect the magnitude of R&D expenditures and thus the rate of technological change. For the purpose of the second, however, R&D expenditures may be given and in that case we just look at the nature of inventive activity, not its rate.

Salter (1960, pp. 43-44) attacked Hicks' assertions. He denied the presence of any such mechanism where relative factor-prices could influence the nature of technological change and most of the profession, somehow, agreed with him as is clear from Rosenberg's evaluation (1976, p. 109):

> "Salter's position may be quoted as representative of a larger genus. Speaking of Hicks' theory of induced inventions, he stated: If... the theory implies that dearer labour stimulates the search for new knowledge aimed specifically at saving labour, then it is open to serious objections. Entrepreneur is interested in reducing costs in total, not particular costs such as labour costs or capital costs. When labour costs rise any advance that reduces total cost is welcome, and whether this is achieved by saving labour or capital is irrelevant. There is no reason to assume that attention should be concentrated on labour-saving techniques."

Salter's objection to Hicks' position stems mainly from the way he defines the production function, a definition which has come under strong attack. We shall show that his criticism of Hicks' position is unfounded.

Before we do that, it is useful to introduce the concept of the innovation possibility curve (IPC) as developed by Ahmad (1966, pp. 344-357). The IPC is defined as a set of potential production processes (techniques) per unit output that could be developed at a particular time given the state of basic science. Each of those processes is defined by an isoquant which has relatively small elasticity of substitution. Conceived this way, IPC is an envelope of all possible unit isoquants.

Salter, on the other hand, has an isoquant which is analogous to the IPC. He defines the production function as embracing all possible designs conceivable by existing scientific knowledge. In the following Figure C'_{N-1} represents Ahmad's IPC and Salter's isoquant at a particular time. Salter conceded Hicks' first assertion by stating "when labour costs rise any advance that reduces total cost is welcome" (that is a shift of C_{N-1} inwards to let us say C_N).

Salter refused to accept the presence of any mechanism whereby a change in relative factor-prices would cause a bias in the technological change. Given his definition of isoquant, his contention is quite justified. This is fairly obvious in Figure 2.II. Whereas in Ahmad's case a movement from M to N* as a result of factor-price change from P_{n-1} to P'_n would qualify as induced bias in innovation, in Salter's case it would be mere factor-substitution since the isoquants

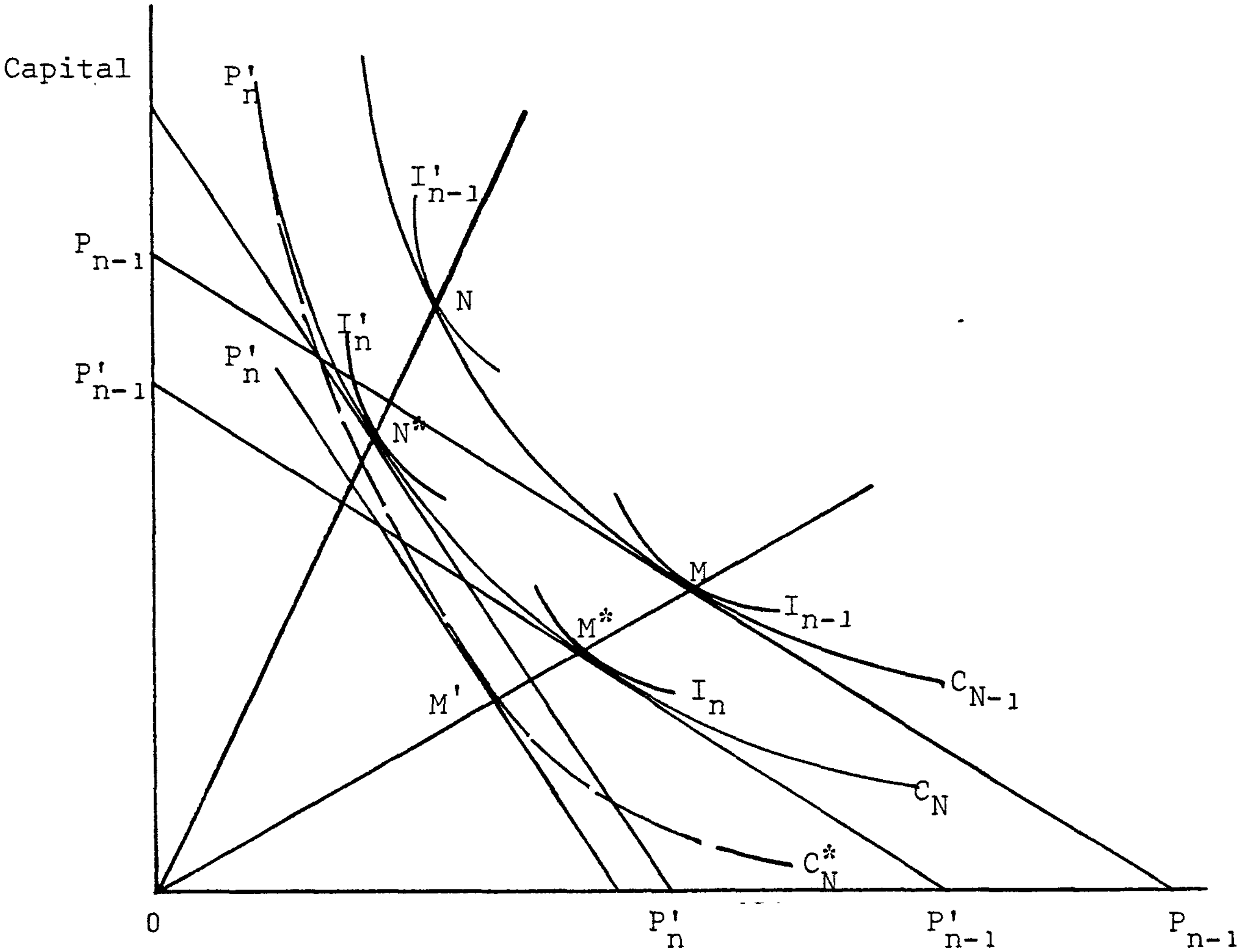

Figure 2.II

Induced Bias and Innovation Possibilities

(or IPC) C_{N-1} is assumed to shift inwards neutrally to isoquant (or IPC) C_N. In Salter's case an inward movement of an isoquant like C^*_N would qualify as a case of induced bias in innovation which, incidently, would be analogous to Ahmad's historical bias in the innovation possibilities.[14] Thus Salter is right when he contends:

> "If...the theory implies that dearer labour stimulates the search for new knowledge aimed specifically at saving labour, then it is open to serious objections."

It is hard to see how relative a factor-price change can make the acquisition of knowledge easier or less costly, and hence cause a bias in the innovation possibilities as a shift like C^*_N would indicate.

Ahmad criticized Fellner, Mansfield, and Salter. However, in his explanation, he dwelt entirely upon the second Hicksian assertion and did not take any position with regard to the first one, i.e., that relative factor-prices affect the rate of technological change.

This failure to tie the two Hicksian assertions together into an analytical framework left induced innovation theory incomplete in that the distinction between the positions of Ahmad and Salter *et al.* simply reduces to different assumptions about the shape of the isoquant (production function).

Ahmad's isoquants, as already pointed out, are characterized by relatively smaller elasticity of substitution as compared to his IPC. Salter, on the other hand, defined his isoquant analogous to Ahmad's IPC. As a result, in his framework, a choice among different designs is disposed of as factor-substitution rather than induced bias in innovation. This position, while accepted by some, is criticized sharply by others.[15] It became an empirical question of measuring the elasticity of substitution to lend validity to either of those positions.

Hayami and Ruttan, working in the field of agricultural economics, took Hicks' position in its entirety as they wrote (1971, p.26-27):

> "We then explore the nature and generation of technical change in agriculture. Explicit attention is given to the forces that influence the rate and direction[16] of technical change. These include, ... the significance of factor endowments, and the interaction between factor endowments and the broader economic environment through the price system" (emphasis mine).

They showed the effect of relative factor-price changes on the rate and direction of technological change with the help of a meta-production function which, in essence, is similar to Ahmad's IPC.[17] They did not substantiate empirically their theoretical proposition that relative factor-price changes affect the rate of technological change, in so far as their empirical work only looked into the effect of relative factor price changes on factor use. In other words, they have only tested induced bias in technological change along Ahmad's lines.

Hayami and Ruttan's work inspired a lot of effort in both refining the theoretical underpinnings, as well as empirical testing of the hypothesis. A natural first step was to provide evidence that Hayami and Ruttan's results did, in fact, suggest induced bias in innovation rather than mere factor-substitution. Binswanger provided an answer by calculating the necessary elasticity of substitution -

the elasticity of substitution that would be necessary to explain the observed difference in the factor ratios - and comparing it with the econometrically estimated elasticity of substitution calculated from the factor demand elasticity following Yair Mundlak's methodology.[18]

Much empirical work has been done on the induced innovation hypothesis for almost all Western European countries since the pioneering work of Hayami and Ruttan[19], and Binswanger has done considerable work in refining the theoretical model of induced innovation. But before we take a look at the direction induced innovation theory seems to be heading, it will be fruitful to see whether the traditional approach can explain the induced innovation theory in the sense of both the rate and direction of technological change.

If a relative factor price change gives rise to the choice of a new technique which uses relatively less of a factor that has become expensive, we shall call it induced bias in innovation. If, moreover, the expenditures to develop the new technique are warranted by the price change itself, it will qualify for the pure case of Hicks' induced innovation.

In Figure 2.III, I_1 and I_2 are two of the set of unit isoquants that form the IPC*. Advances in basic sciences shift the entire IPC inwards closer to the origin. In time period one, I_1 was developed in response to price ratio P_1P_1

that shifted the production point to B from A. Now consider a change in the factor price ratio from P_1P_1 to P_2P_2 (= $P_2'P_2'$ = $P_2^*P_2^*$). For sake of simplicity we assume that no further breakthrough occurs in the basic sciences so that the position of the IPC* remains unchanged.[20] We further assume that the optimal amount of R&D expenditures remains unchanged from the previous period and that development of I_2 is independent of I_1.

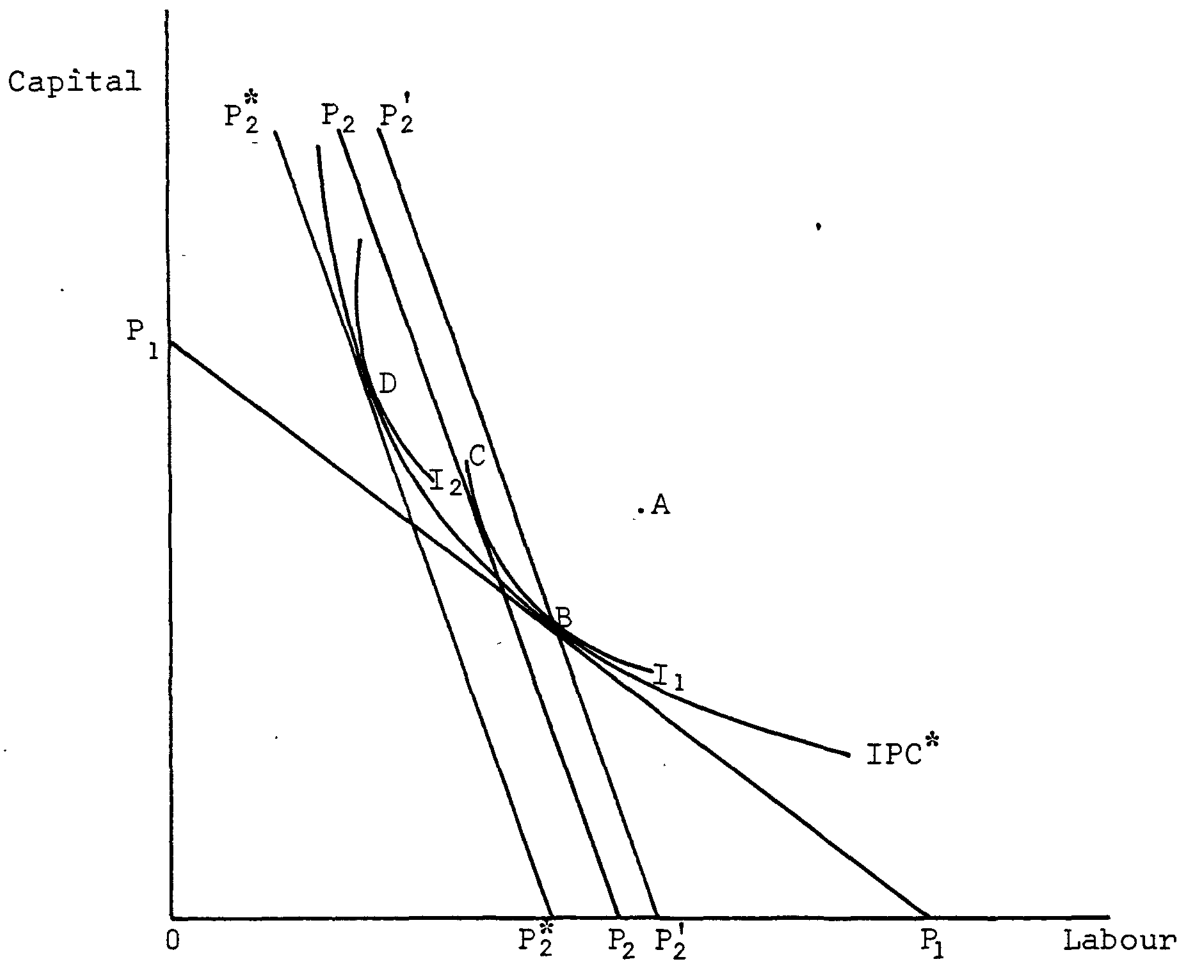

Figure 2.III

Cost-saving and Innovation Possibilities
(adapted from Ahmad's Fig. 1)

A movement from B to C immediately becomes in order since it gives rise to a cost saving of the magnitude $P_2'P_2$ reckoned in terms of labour and assuming that change in relative factor prices is caused by only a change in the absolute price of capital. This is the case of normal factor-substitution. When it comes to the choice of technique for period two, the question is: will the firm develop the technique represented by I_2? The answer can easily be given. Development of I_2 requires an outlay of resources, presumably the same amount as was required for development of I_1 , with reference to point A. The development of I_2 would give rise to a saving in cost to the magnitude of $P_2P_2^*$ for each period. The total cost saving would be the discounted sum of cost savings over the expected lifetime of the technique. If this cost saving warrants the development of I_2 it would be developed.[21] This, then, would be the pure case of Hicks' induced innovation. I_2 is absolutely more labour saving[22] and is induced by a relative factor-price change. Thus we have shown that the traditional Hicksian position is theoretically plausible and that the induced innovation framework could be used to explain it. It remains an empirical question to see if it can be supported by historical observations.

We can now return to the more recent developments of the theory of induced innovation. Binswanger has devoted a lot of effort in refining the theoretical underpinnings and has put forth a model in which market size, factor prices, and cost of research all enter as determinants of rate and direction of technical change.

We have already noted the deficiency in Ahmad's model which does not consider the rate of technological change. According to Binswanger, another shortcoming of different models in the area of induced innovation is that

> "They do not describe how a researcher can guide his work in a more or less labour-saving direction. If a model is to be used for policy purposes, this choice process has to be characterized" (1978, p. 97).

With the help of a portfolio-choice type of model, he shows how the size of market, relative factor prices, and the price(cost) of research activity affect the optimal research project mix and how, in turn, it relates to factor-intensity characteristics of the technology developed as a result.

In Figure 2.IV, II' represents the initial production function. There are, suppose, two research activities, n and m, as shown by arrows, where the length of each arrow shows the change in input-output mix as a result of one unit of research input. Research activity n is labour-saving while m is capital-saving. Isoquant QQ' could be developed if the entire effort was spent on n while R'R could be developed by devoting all the research budget to m. QR, which is envelope of QQ' and R'R is defined as the IPC.

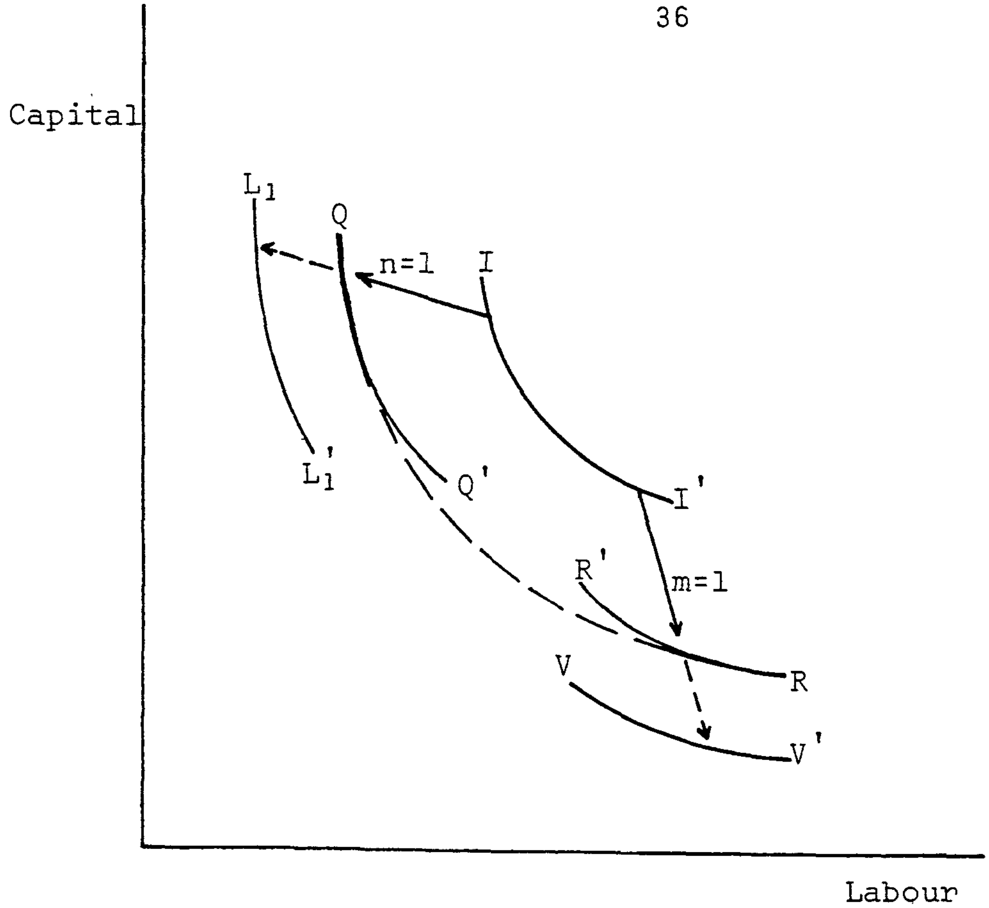

Figure 2.IV

Innovation Possibilities of the Formal Model
(adapted from Binswanger, 1979, p. 102, Fig. 4-4)

A firm making the decision to build a new plant faces the choice of either staying with existing design II' or developing a new one like Q'Q, R'R or some combination of the two. The firm evaluates the costs and benefits and makes its decision accordingly. Corresponding to II', assuming cost-minimizing behaviour and constant returns to scale, there exists a minimum cost function such that;

$$C_o^* = YG_o(R,\tilde{W})$$

where Y is the level of output, R the purchase cost of a unit of capital, and $\tilde{W}$ the discounted wage rate-discounted over the lifetime of the plant.[23] The minimum cost of production (exclusive of research cost) with any other isoquant is thus;

$$C_1^* = YG_1(R,\tilde{W})$$

where subscript 1 denotes the isoquant after research. The research benefits exclusive of research costs are;

$$B = C_0^* - C_1^*$$

Binswanger builds the innovation possibilities of Figure 2.IV into this difference of cost functions such that the benefits of research become a function of R, W, and the levels of n and m;

$$B^* = Y\Psi(R,\tilde{W},n,m)$$

It now becomes a problem of maximizing total research payoffs less research costs, that is, maximizing

$$V = Y\Psi(R,\tilde{W},n,m) - nP_n - mP_m$$

where P_n and P_m are the costs (or prices) per unit of each research activity. Similarly, he expresses the bias of technical change as a function of n and m; and evaluates the effects of changes in the output level, relative factor prices, and the interest rate on the research mix and on the bias corresponding to this mix.

Binswanger has, thus, made induced innovation theory a topic in investment theory in general, where R&D expenditures, and the rate and direction of inventive activity are determined simultaneously.

In the next chapter, we shall attempt to build a simple model of induced technological change where R&D expenditures in an industry are proposed to be a function of market size - à la Schmookler, and of changes in relative factor prices - à la Hicks.

CHAPTER TWO: FOOTNOTES

1

See for example, Schmookler, J., *"The Changing Efficiency of the American Economy, 1869-1938"*, Review of Economics and Statistics, (Aug., 1952); Abramovitz, M., *"Resource and Output Trends in the United States Since 1870"*, American Economic Review (May, 1956); Solow, R., *"Technical Change and the Aggregate Production Function"*, Review of Economics and Statistics (Aug.,1957); Massell, B., *"Capital Formation and Technological Change in U.S. Manufacturing"*, Review of Economics and Statistics (May, 1960).

2

He defines technology as "society's pool of knowledge regarding the industrial arts. It consists of knowledge used by industry regarding the principles of physical and social phenomena...knowledge regarding the application of these principles to production...and knowledge regarding the day-to-day operations of production"(1968, 10-11).

3

According to Schmookler, "Technological change takes place when an enterprise produces a good or service or uses a method or input that is new to it" (1966, p. 2).

A similar definition is given by Archer. "Technological change is taken to cover new or improved industrial products or commercial services, new or improved materials, new or improved processes and any other change arising from the application of organized knowledge to the production and supply of goods and services", *In: Technological Innovation and the Economy"*, Maurice Goldsmith, ed., (Wiley, 1970).

Schumpeter's definition of technological change is synonymous with innovations: "We will now define innovation more rigorously by means of the production function - this function describes the way in which quantity of products varies if quantities of factors vary. If, instead of quantities of factors, we vary the form of function, we have an innovation" (1939, pp. 87-88).

4 Robert A. Charpie's definition seems a little comprehensive but also more abstract. "I shall use the word 'invention' in the sense of 'to discover' - to discover a phenomenon, to discover a fact, to discover or create an idea. This may be conception with paper and pencil; it may be observation of a physical or biological phenomenon; or it may be articulation of an idea in the form of a specific piece of hardware or a complete system of equipment" (Charpie in Goldsmith, 1970, p. 2).

According to Charpie's definition most of the basic research findings would qualify as inventions.

5 Professor Rosenberg (1976, p. 262) wrote, "Schmookler's analysis is so rich and so suggestive that it has to be the starting point for all future attempts to deal with economics of inventive activity and its relationship to economic growth." Acknowledgement of that intellectual debt aside, this section leans heavily on Professor Schmookler's work.

6 Some of his studies are: *"The Changing Efficiency of the American Economy, 1869-1938"*, Review of Economics and Statistics (Aug., 1952), 214-231; *"Invention, Innovation, and Competition"*, Southern Economic Journal (April, 1954), 380-385; *"The Level of Inventive Activity"*, Review of Economics and Statistics (May, 1954), 183-190; *"Bigness, Fewness, and Research"*, Journal of Political Economy (Dec., 1959), 628-632; *"Changes in Industry and in the State of Knowledge as Determinants of Industrial Invention"*, *In:* Richard R. Nelson (ed.) *"The Rate and Direction of Inventive Activity: Economic and Social Factors"* (Princeton, N.J., Princeton University Press, 1962) 195-232; *"Economic Sources of Inventive Activity"*, Journal of Economic History (March, 1962), 1-20; *"Determinants of Inventive Activity"*, with O.H. Brownlee, American Economic Review (Sept., 1963), 725-729; *"Technological Change and Economic Theory"*, American Economic Review (May, 1965), 333-341; *"Technological Change and the Law of Industrial Growth"*, *In: "Patents, Invention, and Economic Change"* (Cambridge: Harvard University Press, 1972), 70-84.

7 For example, see his *"Catastrophe and Utilitarianism in the Development of Basic Science"*, in Richard A. Tybout, (ed.) *"Economics of Research and Development"*(Ohio State University Press, 1965), 19-33; reprinted in his

"Patents, Invention, and Economic Change" (Harvard University Press, 1972), 47-59.

8 Kuznets, S. *"Secular Movements in Production and Prices"* (Boston: Houghton Mifflin Co., 1930); and Salters, W.E.G. *"Productivity and Technical Change"* (Cambridge: Cambridge University Press, 1960), 133-134.

9 We could have a horizontal supply curve as in the case of constant returns to scale without affecting the argument.

10 The demand curve may shift to the right over time due to a rise in income or better understanding of the product but that comes in response to a shift in the supply curve.

11 Rosenberg, N. *"Perspectives on Technology"*(Cambridge: Cambridge University Press, 1976) Chapter 15.

12 Kennedy's (1964) theory of induced bias in innovation looks at the role of relative factor shares in the induced invention.

13 It should nevertheless be pointed out that he did recognize the role of relative factor prices in affecting the rate of technological change. Commenting on his own definition of technological change (see footnote 3) he wrote in a footnote, "This definition departs from another often used. The latter limits 'technical change' to change in technique resulting from acquisition of knowledge new to the enterprise and excludes thereby changes in technique occasioned by price changes. While these distinctions are well worth making, the terminology chosen seems inappropriate. It seems only natural to define any change in technique as a technical change. The alternative definition can result in the paradox that a technological change (change in knowledge) which becomes economical only after a change in relative prices will never result in a "technical change (change in practice) no matter how widespread the use of knowledge in question becomes." He, however, did not give that alternative definition.

14 Whereas in the case of Ahmad, relative factor price changes would necessarily change the factor intensities; in Salter's induced bias in innovation, the line factor intensities

may remain unchanged as would be the case at point M'.

Whenever capital becomes relatively cheap, several kinds of adjustments could take place to keep $MP_L/P_L = MP_K/P_K$. One is to reduce the marginal product of capital as would be the case at point N*. On the other hand, MP of labour could increase as would happen at point M'.

15 Ahmad commented in his footnote, "It may be argued that all existing knowledge, including knowledge about the result of innovation, should be considered part of the production function, and that therefore the historical innovation possibility curve is itself a kind of isoquant. This is merely a matter of names, as long as we know the difference between the two concepts, viz., the one including and the one excluding the result of inventive activity" (1966, p. 347). Thus as long as a relative factor price change leads to a shift to a new isoquant, his exposition of the idea of price induced bias is secure.

Professor Rosenberg criticized Salter as well, commenting on the way Salter defined the production function, he argued, "Now, I want to argue, when we take this last step with Salter, we are really allowing factor substitution to swallow up much of technological change" (1976, p. 65). It would not be an exaggeration if we suggest that his view is becoming representative of a larger genus.

16 They, unlike Schmookler, use direction as synonymous to bias, and we use the two interchangeably.

17 See their, *"Agricultural Development: An International Perspective"* (Baltimore: Johns Hopkins University Press, 1971) 82-85. In fact, they have now abandoned the term meta-production function to describe the innovation possibilities in favour of Ahmad's IPC (see footnote 4 in Binswanger *et al.*, 1978, p. 46.

18 He found that the differences between the two sets of elasticities were too large to admit factor substitution as the only explanation for the observed changes in factor intensities (see Binswanger *et al.*, 1978, pp.73-77).

19 See Chapter 3 of Binswanger *et al.* (1978) for a summary of those studies.

[20] This assumption is not crucial to our results as will be seen in the next chapter when we present our formal model.

[21] Throughout our analysis, we shall assume that the firm making R&D expenditures appropriates all the benefits accruing as a result of the development of new technique.

[22] We shall have a case of relative labour-saving as well, when we include the shifts in IPC in our analysis. That would happen when the new production point shifts inwards where it saves on both the inputs, but saves more labour relative to capital.

[23] This is based on W.E. Diewert's *"An Application of the Shephard Duality Theorem: A Generalized Leontief Production Function:*, Journal of Political Economy 79 (May-June, 1971) 481-505. In view of his use of the purchase price of a unit of capital, Binswanger has not included the rental cost of capital in his analysis.

CHAPTER THREE

A MODEL OF INDUCED TECHNOLOGICAL CHANGE

3.1. Induced Technological Change

By induced technological change we mean that the rate of technological change is governed by the interplay of economic forces internal to the system. Thus, a situation where the level of inventive activity is determined, in general, by economic variables would qualify as a case of induced innovation and hence technological change. In that context, the role of market size and relative factor price changes, as presented in the economics literature, has been reviewed in the previous chapter.

Inventive and innovative activities, though they could easily be regarded as separate activities, are considered part of the chain leading to technological change. For our purposes it is not relevant to make a distinction between them. We have considered both of them and development work as a whole process, the end result of which emerges as new processes of producing existing goods or entirely new goods.

The essential feature of the process is either reduction in cost of producing existing goods or new goods that satisfy human wants more efficiently and thus enhance welfare in general. To illustrate the point we again resort to the IPC. As technological change takes place, the IPC for a unit rate of output shifts inward. This is shown as a shift to IPC* in Figure 3.I. Usually it is thought that

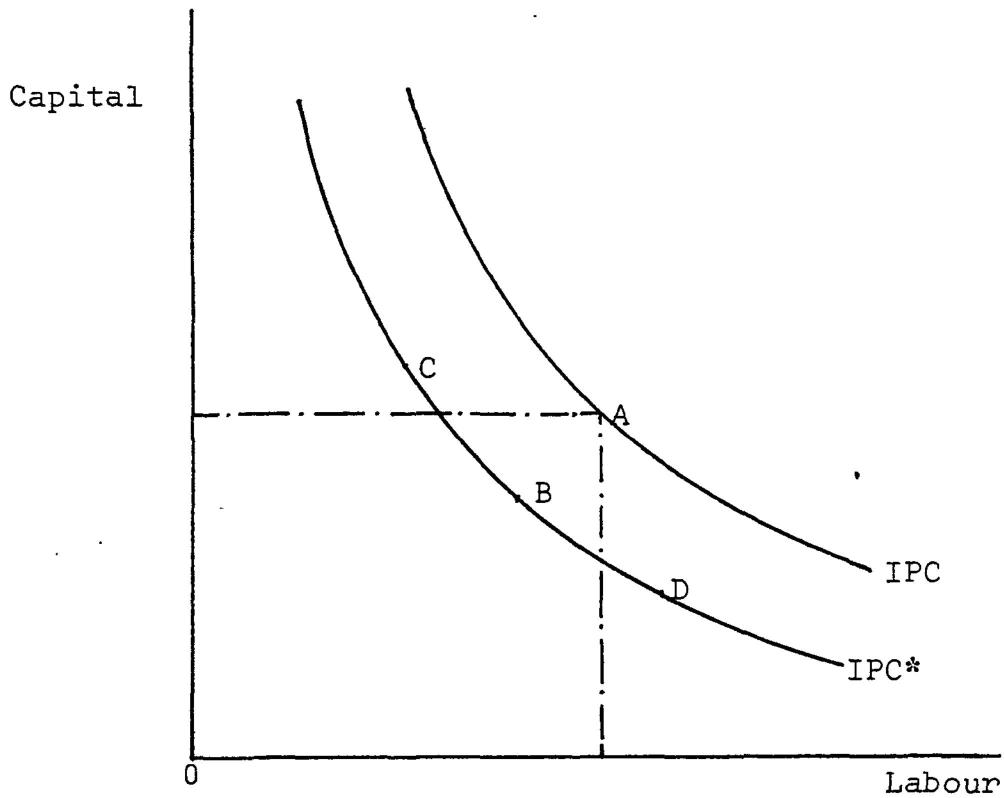

Figure 3.I

Inwards Shift of Innovation Possibility Curve

technological change reduces all the input requirements, as would be the case if the production point moves to 'B'. In this case we would like to know the relative factor-saving realized as a consequence of technological change. However, this situation may not always occur. At point C capital requirements increase at the expense of a reduction in labour requirement and the opposite occurs at point D. What point is chosen is dependent upon relative factor prices.

The inward shift of the IPC represents a resource using activity. To what extent the IPC shifts inwards is determined by the expenditures on R&D. Thus, a particular IPC corresponds to a given level of R&D expenditure. The higher the expenditures the greater the magnitude of movement. Though this point arouses little dispute, nevertheless, it calls for a clarification. R&D is an input in the process that leads to technological change whereas our IPC is in some sense the output of that process and there is no guarantee, given the uncertainties inherent to that process, that the relationship between input and output is stable. In other words, it is not at all certain that a certain level of input will yield a particular level of output across time and space. It may differ from industry to industry and from time to time in the same industry.[1] It needs to be pointed out that this renders the task of making concrete statements about the rate of technological change on the basis of the level of R&D expenditures rather difficult. Nevertheless, acknowledging the limitations this imposes on the present analysis, it is interesting to pursue the induced technological change hypothesis for the following reasons.

First, studies exploring the input-output relationship of the sort we have just described have shown that there is some evidence of a systematic relationship between the efforts expended by the firms (R&D expenditures), and the results achieved (the number of patents or important inventions).[2]

Second, given our concern with induced technological change, and given that the latter is a probe into the response of economic agents to the signals indicating a need for adjustment to changes in basic knowledge, market forces, and/or consumer income and preferences, it is our belief that R&D expenditures represent a more appropriate indicator of this response than the number of patents-à la Schmookler.

3.2. Demand for R&D Expenditures

Having determined the importance of R&D expenditures in determining the rate of technological change, we proceed to evaluate the factors that govern the level of these expenditures. We shall begin by hypothesizing that the level of R&D expenditures is a function of the following variables:

$$RD = f(y, w, q, PRD, \frac{KO}{YO}, \frac{LO}{YO}, t) \qquad (1)$$

where RD = real R&D expenditures,

y = real output,

w = wage rate,

q = user cost of capital,

PRD = price of R&D activity,

YO = initial output level,

KO = initial capital stock,

LO = initial employment level, and

t = time.

It should be recalled that the position of the IPC is determined by the level of R&D expenditures. Let [τ] be an index of possible R&D activities pertaining to the IPC for a given level of R&D expenditures. Each of these activities lead to a cost function (isoquant) $C_\tau(y,w,q)$.[3] IPC is the envelope of these isoquants and corresponds to a cost function:

$$C = \min_\tau C_\tau(y,w,q) = C(y,w,q, RD, \frac{KO}{YO}, \frac{LO}{YO}, t) \tag{2}$$

where KO/YO, LO/YO are included to incorporate the original state of technology or in other words, to identify the initial IPC.[4] The significance of 't' will become clear in a short while. We assume that 'C' is homogeneous of degree one in w and q.

The objective of the firm is to achieve maximum cost reduction adjusted for the level of R&D expenditures, ie., max $(C^o-C-R\&D)$ or min $(C+R\&D)$, where C^o is the initial level of cost of production C, the new cost function, and R&D represents cost of Research and Development. In other words, it requires minimization of

$$C(y,w,q,RD,\frac{KO}{YO},\frac{LO}{YO},t) + RD \times PRD \tag{3}$$

over the level of R&D expenditure. The following optimality condition needs to be satisfied:

$$\frac{\partial C}{\partial RD}(y,w,q,RD,\frac{KO}{YO},\frac{LO}{YO},t) = -PRD \qquad (4)$$

which yields a demand function for R&D expenditures as

$$RD = f(y,w,q,PRD,\frac{KO}{YO},\frac{LO}{YO},t) \qquad (5)$$

where 'f' is assumed to be homogeneous of degree zero in w,q, and PRD.

An alternative specification has been proposed by Nadiri (1979), derived from a production function one of whose arguments is the stock of R&D. Nadiri has specified a production function of the following kind:

$$Q_t = AK_t^{\alpha_1} L_t^{\alpha_2} R_t^{\alpha_3} e^{\rho t}$$

where Q,K,L, and R are level of output, and stocks of capital, labour, and R&D, respectively. Nadiri then proceeded to specify and estimate the demand for R&D stock which is based on output, factor prices, and the price of R&D activity.[5] Whereas he specified and estimated the stock demand, our concern is with the flow demand, ie., R&D expenditures. It is important to point out that Nadiri's specification was based on Nadiri and Rosen (1973) though R&D stock itself was not explicitly treated as a factor of production in that work.

Nevertheless, Nadiri treated R&D stock as analogous to capital stock whose demand function was derived from optimization under the cost-minimization assumption. In addition, he applied the concept of depreciation to the R&D stock and estimated it by the following formulae:

$$RD_t^s = RD_t + RD_{t-1}^s(1-\delta)$$

where superscript 's' denotes the stock variables, and δ is the depreciation rate. He picked an arbitrary depreciation rate of ten percent but did not explain what he really meant by depreciation of the stock of knowledge. He, however, had to do this to justify the existence of R&D expenditures even when none of the explanatory variables changed (similar to existence of investment even in a situation where capital stock does not change). If an industry is in equilibrium, no change in any explanatory variables would imply no change in the stock of R&D. But there still exists a flow of R&D that needs to be explained. Thus, Nadiri treated R&D stock analogous to capital stock where depreciation of knowledge required new R&D expenditures. However, the question immediately arises as to what he means by depreciation of knowledge. He did not give any explanation. There is no conceptual similarity between depreciation of R&D and depreciation of capital. An explanation of continuing R&D has to be sought in the ever <u>changing state of knowledge</u> as time goes on. In other words, the answer has to be given in the recognition of the importance of the supply side of inventive activity as has been explained in the previous chapter. It is not that knowledge acquired over the past somehow deteriorates or depreciates that R&D expenditures are undertaken, rather it is the acquisition of new knowledge and the consequent possibility of producing the existing output more efficiently, with less cost, that makes it desirable to undertake R&D expenditures. Nadiri's depreciation of R&D stock has to be understood to represent the obsolescence of the older knowledge in the sense just described. The new knowledge makes the older knowledge relatively less useful. The ever-changing state of knowledge is viewed as a function of time. This is the reason for the inclusion of 't' in our formulation of the induced technological change hypothesis.

3.3. Output of the Industry

Schmookler did not build a theoretical model where output could be shown as affecting the level of inventive activity though his empirical observations strongly support that proposition. In our model it is fairly obvious that level of output in an industry would affect the demand for R&D expenditures. R&D expenditures essentially reduce the unit cost of producing existing output. The total cost reduction, thus, will be higher the higher the level of output on which that reduction is applicable. We can get dRD/dy by totally differentiating equation (4), and considering only dy ≠ 0, and dRD ≠ 0,

$$\frac{\partial^2 C}{\partial RD \partial y}\, dy + \frac{\partial^2 C}{\partial RD^2}\, dRD = 0$$

or

$$\frac{dRD}{dy} = -\frac{\partial^2 C/\partial RD \partial y}{\partial^2 C/\partial RD^2} \tag{6}$$

Given that $\partial^2 C/\partial RD\partial y < 0$,i.e., with an increase in R&D marginal cost decreases for a given level of output. On the other hand, assuming $\partial^2 C/\partial RD^2 > 0$ to reflect decreasing returns to R&D activity as has been shown by Evenson and Kislev (1975)[6]; we get

$$\frac{dRD}{dy} > 0.$$

Effects of factor price changes are difficult to discern. However, we shall discuss those later.

3.4. Initial State of Technology

KO/YO and LO/YO have been incorporated into the model to identify the initial state of technology. Technological change in an industry necessarily reduces at least one of the input requirements for a unit output. As a result, at least one of KO/YO and LO/YO changes. That change in input requirements depends on the initial state of technology in the sense that the higher the initial input requirements are, the more rudimentary the technology is, and there is more room for improvement in it. Thus the initial input requirement may affect the R&D expenditures.

Totally differentiating (4) and considering $d(LO/YO) \neq 0$, $d(KO/YO) \neq 0$, and $dRD \neq 0$,

$$\frac{\partial^2 C}{\partial RD \partial (LO/YO)} d(LO/YO) + \frac{\partial^2 C}{\partial RD^2} dRD = 0$$

and

$$\frac{\partial^2 C}{\partial RD \partial (KO/YO)} d(KO/YO) + \frac{\partial^2 C}{\partial RD^2} dRD = 0$$

from which we get;

$$\frac{dRD}{d(LO/YO)} = - \frac{\partial^2 C/\partial RD \partial (LO/YO)}{\partial^2 C/\partial RD^2}$$

and

$$\frac{dRD}{d(KO/YO)} = - \frac{\partial^2 C/\partial RD \partial (KO/YO)}{\partial^2 C/\partial RD^2} \qquad (7)$$

We have already noted that $\partial^2 C/\partial RD^2 > 0$; thus the signs of $dRD/d(LO/YO)$ and $dRD/d(KO/YO)$ depend on the signs of $\partial^2 C/\partial RD \partial (LO/YO)$ and $\partial^2 C/\partial RD \partial (KO/YO)$, respectively. But $\partial^2 C/\partial RD \partial (LO/YO) < 0$ implies that marginal cost-saving is higher the larger is LO/YO and vice versa if it is greater than zero. A similar interpretation can be given to $\partial^2 C/\partial RD \partial (KO/YO)$.

In the case where $\partial^2 C/\partial RD \partial (LO/YO)$ and $\partial^2 C/\partial RD \partial (KO/YO) < 0$, the signs of $dRD/d(LO/YO)$ and $dRD/d(KO/YO)$ would be as follows:

$$\frac{dRD}{d(LO/YO)} = - \frac{\partial^2 C/\partial RD \partial (LO/YO)}{\partial^2 C/\partial RD^2} > 0$$

and $$\frac{dRD}{d(KO/YO)} = - \frac{\partial^2 C/\partial RD \partial (KO/YO)}{\partial^2 C/\partial RD^2} > 0.$$

Alternatively,

$$\frac{dRD}{d(LO/YO)} < 0$$

$$\frac{dRD}{d(KO/YO)} < 0$$

in the case where $\partial^2 C/\partial RD \partial (LO/YO) > 0$, and $\partial^2 C/\partial RD \partial (KO/YO) > 0$, respectively. The postulated relationship becomes clear once we look at Figure 3.II which illustrates the relationship between the initial state of technology and R&D expenditures derived from equilibrium condition (4). We assume $RD_3 > RD_2 > RD_1$. If LO/YO and KO/YO are large, and if dRD/d(LO/YO) and dRD/d(KO/YO) are greater than zero, there is more incentive to R&D because of "rudimentary technology". In other words, a greater unit cost reduction is potentially achievable or there is more room for improvement of technology. If, on the other hand, dRD/d(LO/YO) and dRD/d(KO/YO) are less than zero, there is less room for improvement because of "mature technology". Later on in an alternative specification we have tried unit cost of output as an indicator of the initial state of technology.

We can go a step further from our present reasoning to see what kind of technological change, capital- or labour-saving is implied by the argument we have so far been making. Consider a situation where

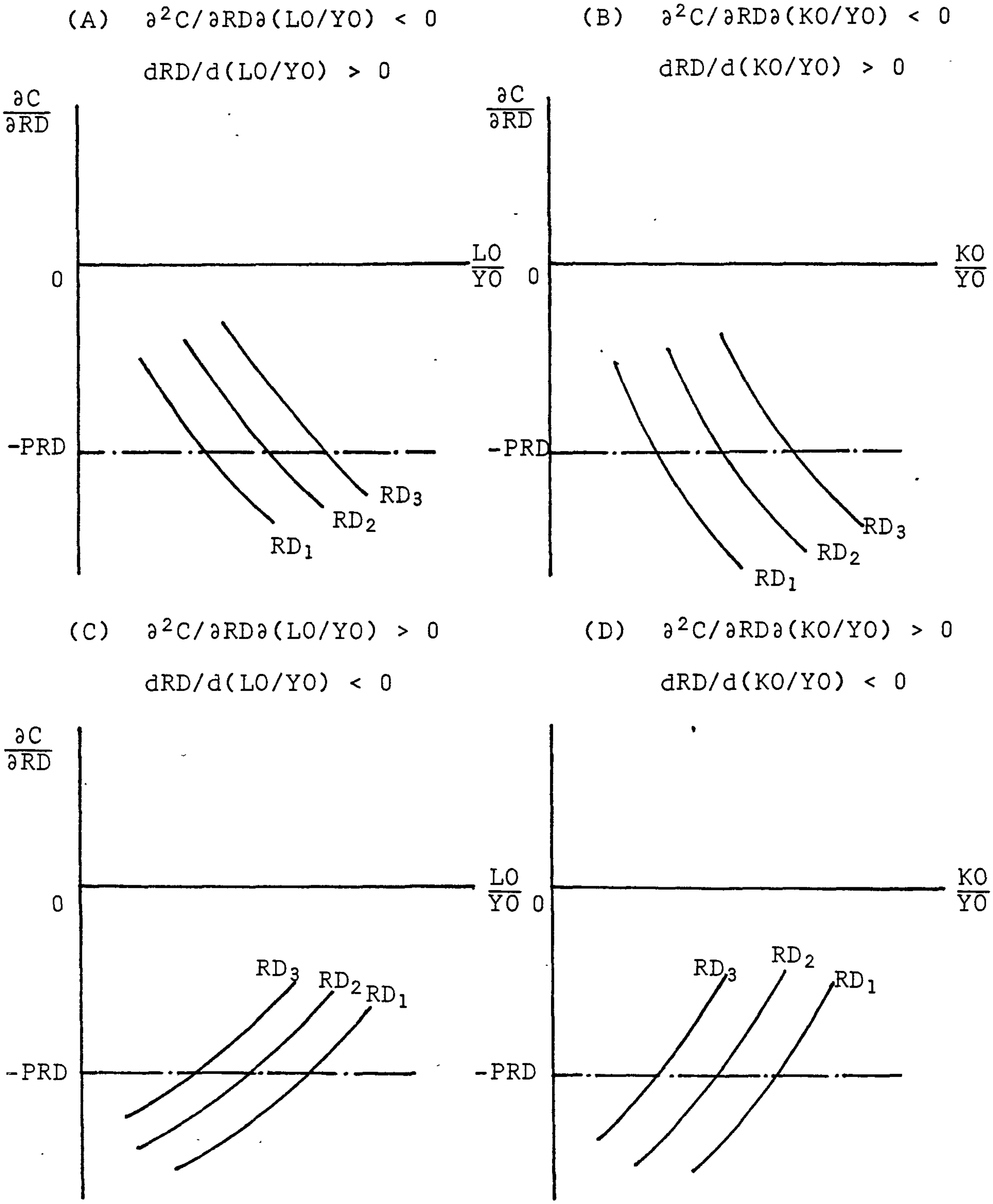

Figure 3.II

State of Technology and R&D Expenditures

$$dRD/d(LO/YO) > 0$$

and

$$dRD/d(KO/YO) < 0$$

which would imply that a higher initial LO/YO would result in more R&D expenditures. Thus in Figure 3.III, the new IPC would be $IPC_1(RD_1)$, $IPC_1(RD_2)$, or $IPC_1(RD_3)$ depending on whether we started from point A,B, or C, respectively, on the old IPC, IPC_0. The presumption that $RD_3 > RD_2 > RD_1$ still holds. We would move to A',B', and C' from A,B, and C,

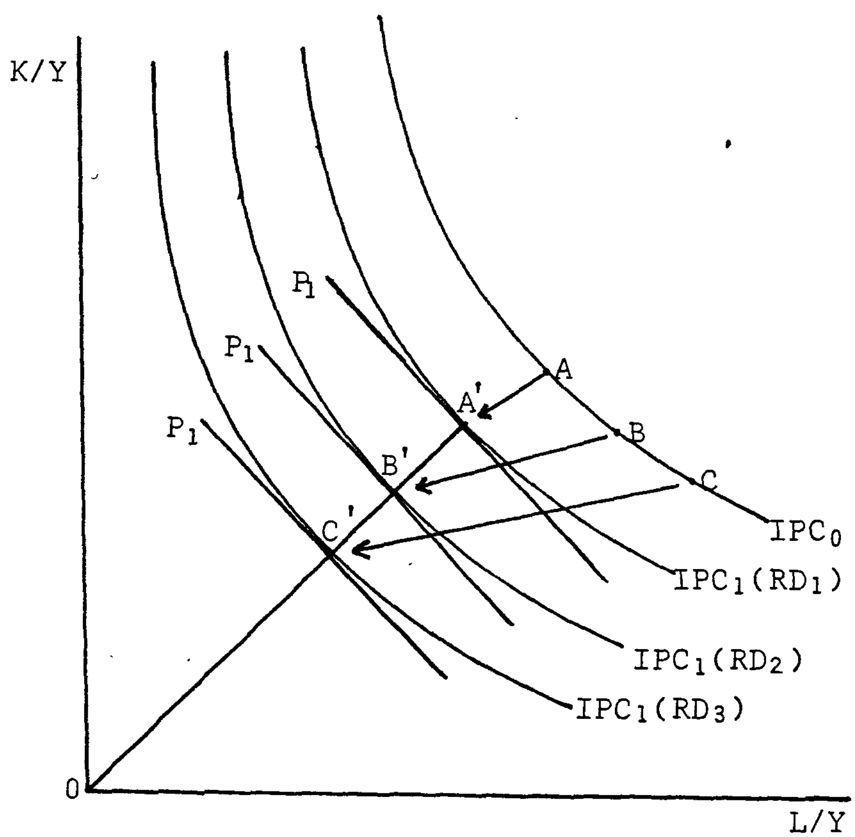

Figure 3.III

State of Technology and Shift of the IPC respectively. In this case technological change will necessarily be absolutely labour-saving the more labour-using the initial technology was. There was more room for improvement due to initial technology being more rudimentary. The crucial assumption in this whole argument is that innovation possibilities are neutral or $IPC_1(RD_1)$, $IPC_1(RD_2)$, and IPC_1 (RD_3) are all neutral to each other which was insured by points A', B', and C' lying on the same ray from origin in response to a given factor-price ratio P_1P_1. However, the new innovation possibility curves may or may not be neutral to the original IPC, IPC_0.

The case of absolute capital-saving technological change exists when;

$$dRD/d(LO/YO) < 0$$

and

$$dRD/d(KO/YO) > 0$$

Nothing, however, could be said where dRD/d(LO/YO) and dRD/d(KO/YO) are both either negative or positive.

An alternative specification for the initial state of technology would be the unit cost of output in which case (4) would become,

$$\frac{\partial C}{\partial RD}(y,w,q,RD,C_0,t) = -PRD \qquad (8)$$

where C_0 is the initial unit cost and the remaining arguments are the same. The resultant R&D demand function would be

$$RD = g(y,w,q,PRD,C_0,t) \tag{9}$$

which possesses the same properties as the original demand function. To get dRD/dC_0, we totally differentiate (8) and assume only $dC_0 \neq 0$, and $dRD \neq 0$,

$$\frac{\partial^2 C}{\partial RD \partial C_0} dC_0 + \frac{\partial^2 C}{\partial RD^2} dRD = 0$$

Thus

$$\frac{dRD}{dC_0} = - \frac{\partial^2 C/\partial RD \partial C_0}{\partial^2 C/dRD^2} \tag{10}$$

Recalling that $\partial^2 C/\partial RD^2 > 0$, the sign of dRD/dC_0 depends on the sign of $\partial^2 C/\partial RD \partial C_0$. A negative sign of $\partial^2 C/\partial RD \partial C_0$, which would imply an increasing MC saving from R&D when C_0 is higher, results in (10) being positive, and vice versa when $\partial^2 C/\partial RD \partial C_0$ is positive. This relationship is depicted in Figure 3.IV, again assuming that $RD_3 > RD_2 > RD_1$.

In the case where $dRD/dC_0 > 0$, the higher the initial unit cost -- "rudimentary technology" -- the more is the room for improvement and consequently higher the incentive for R&D. A negative sign of dRD/dC_0 indicates a smaller room for improvement in technology or "mature technology".

3.5. State of Knowledge

Earlier on we touched upon the subject of ever-changing state of knowledge as time goes on. That was said to be the

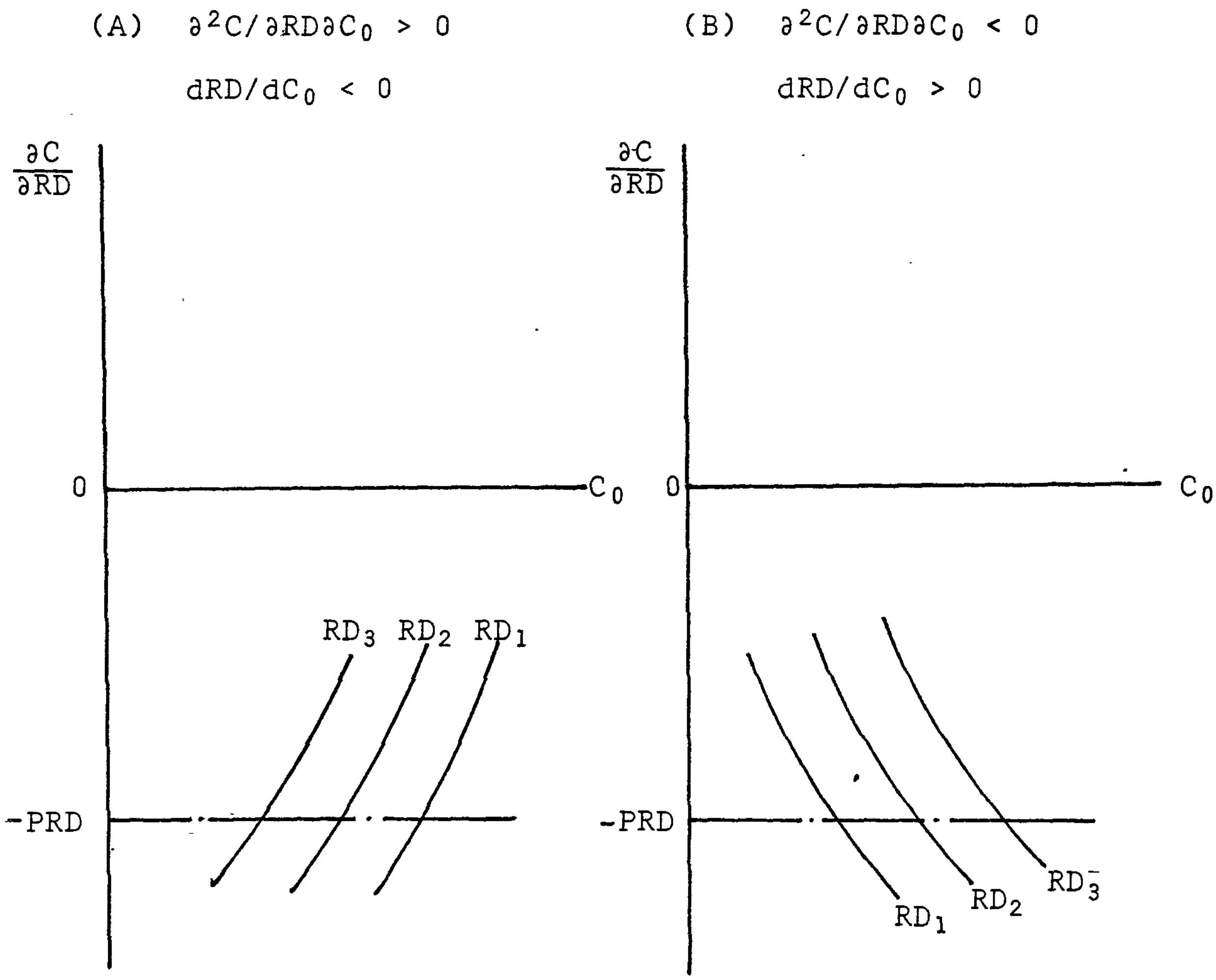

Figure 3.IV

State of Technology and R&D Expenditures

reason to include 't' in our demand function for R&D. The ever-changing state of knowledge could be understood as a product of basic research which is normally recognized as the part of R&D activity motivated essentially by non-economic considerations.[7]

As the state of knowledge (basic sciences) changes, the same level of R&D expenditures would cause a greater reduction in cost if not carried out today but at a later stage. If we totally differentiate (4) and analyze the situation where $dRD \neq 0$, and $dt \neq 0$,

$$\frac{\partial^2 C}{\partial RD \partial t} dt + \frac{\partial^2 C}{\partial RD^2} dRD = 0$$

or

$$\frac{dRD}{dt} = - \frac{\partial^2 C/\partial RD\partial t}{\partial^2 C/\partial RD^2} \qquad (12)$$

in which $\partial^2 C/\partial RD\partial t < 0$ - as time goes on same R&D expenditures cause greater reduction in cost - and $\partial^2 C/\partial RD^2 > 0$ as has already been shown, so;

$$\frac{dRD}{dt} > 0$$

3.6. Relative Factor Prices and the Diagrammatic Representation of the Model

In the previous chapter (Figure 2.III) we saw that a relative factor price change can also influence the level of R&D expenditures. Indeed it can further be shown that it is not only the relative factor price but also the absolute price levels that may bear on the R&D expenditures. In the following figure we attempt to present the model of induced technological change and show the role of the different variables that we have been discussing so far.

Consider Figure 3.V, where IPC_0 and IPC_1 are two innovation possibility curves which are assumed to be

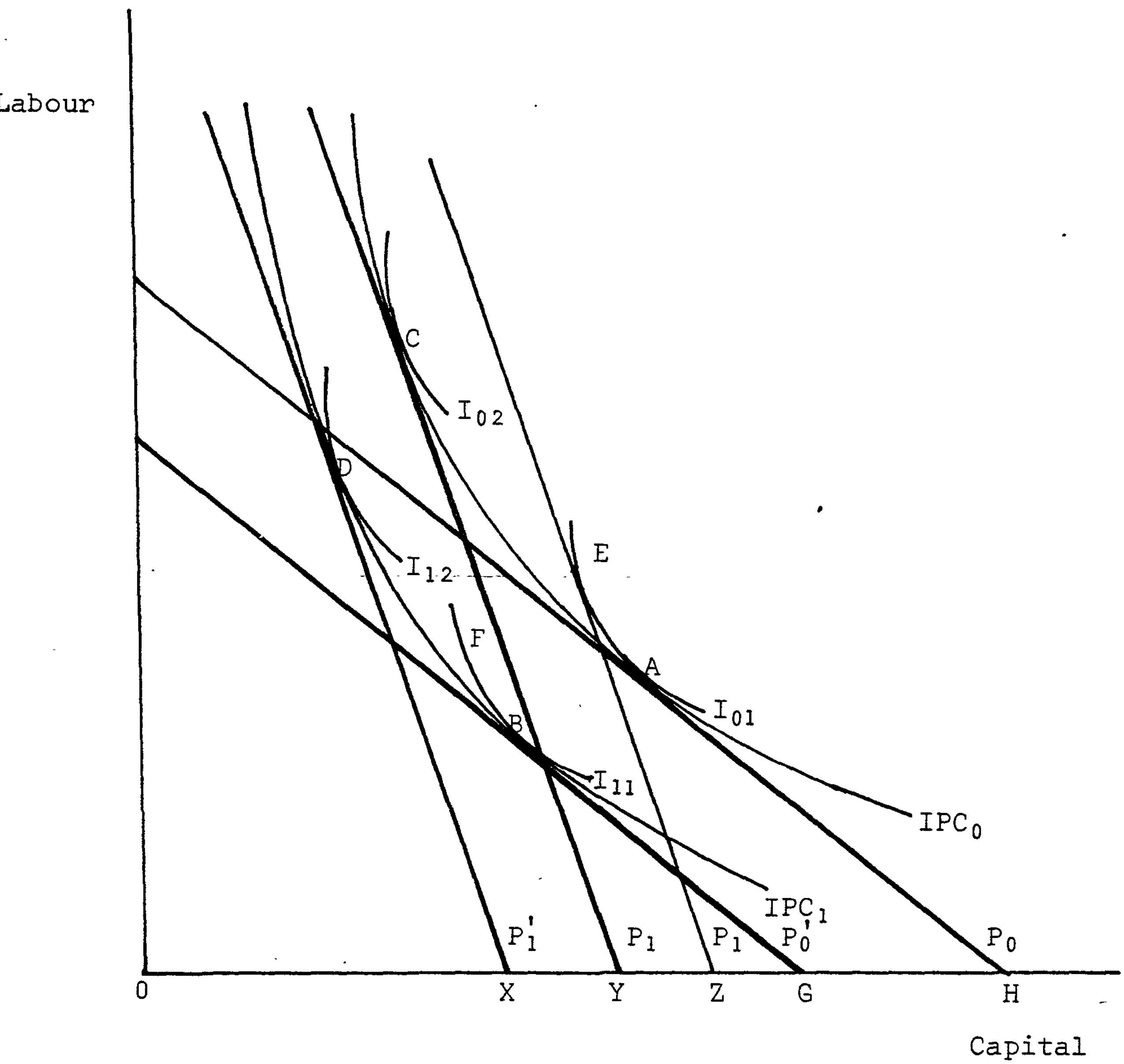

Figure 3.V

Model of Induced Technological Change

historically neutral to each other. I_{01}, I_{02}, I_{11}, and I_{12} are all isoquants for a unit rate of output and neutrality of I_{01} to I_{11} and I_{02} to I_{12} is assumed. When IPC_0 was conceived, the price ratio being P_0 resulted in choice of 'A' as the production point on isoquant I_{01}. A change in the state of knowledge made IPC_1 the potential IPC for the next period which required a fixed amount of expenditure on R&D to be incorporated into production techniques which in turn would give rise to cost saving. That cost saving depends on the level of output, the level of factor prices and the change in relative factor prices. Let us see how.

Suppose relative and absolute factor prices remain unchanged. On the new IPC_1, the optimal production point is 'B' on isoquant I_{11}. Reduction in unit cost as a result of move from A to B is given by GH reckoned in terms of capital. If the level of output on which that reduction applies is sufficient to warrant the required R&D expenditures the production point would move from 'A' to 'B'. If not, some other point in-between A and B will be chosen and in extreme circumstances no move may take place. Now, visualize a situation where level of output was not sufficient to warrant the required R&D expenditures but allow for a higher level of factor prices with relative factor prices still unchanged. In that case, since level of prices enters the production cost (see equation (2)), even that lower level of output may warrant the required expenditures to make a move to production point B. The crucial variables are the factor price-R&D price ratios.

Now, consider the case where relative factor prices change let us say from P_0 to P_1. In the short run, this would result in a change in the production point from A to E (normal factor-substitution). The optimal production point on IPC_1 under the new factor price regime is D. Cost-saving entailed by a move from E to D, still reckoned in terms of capital, is represented by XZ (assume that only labour's absolute price changed). If the level of output on which this cost-saving is applicable is sufficient to warrant the required R&D expenditure there is no problem. The move from E to D would be made, otherwise the production point would move somewhere in-between - which essentially means that the relevant IPC would be different from IPC_1. Consider, however, a situation where with unchanged relative and absolute prices the move from A to B was not warranted by the existing level of output. In other words, the unit cost-saving of GH was not enough to cover the R&D expenditures needed for the movement A to B. But with a change in relative factor prices from P_0 to P_1 the cost-saving XZ as compared to GH became sufficient to cover those expenditures. This would, then, result in a shift of production point to D.

On the other hand, it is also possible that while the move from A to B without a change in relative factor price was profitable, with relative factor price change it may become unprofitable to move the production point to D. These situations demonstrate the conditions which may exist that make it difficult to predict the signs of the derivatives of the demand function of R&D with respect to prices of the inputs.

Similarly, we can imagine a situation where given the level of output and relative factor price change, a move to D would not be profitable unless the absolute factor prices were higher, though in that case we face an index number problem in reckoning the cost-saving.

Our model can easily be viewed as a dynamic model owing to the ever-changing state of knowledge. As a consequence only one point on a particular IPC is relevant. Once that point is chosen, the entire IPC becomes irrelevant. Consider, for example, IPC_0 on which point 'A' was chosen. After that choice is made the entire IPC_0 becomes irrelevant because next time it is IPC_1 which becomes the relevant one. This can be further clarified by assuming, as we did in the preceding chapter, that movement to 'C' as well as 'D' requires the same amount of expenditures - and there is no reason why development of technique I_{02} should be any cheaper than I_{12} - so that it is inefficient to develop I_{02} once the change in the basic state of knowledge has made it possible to develop I_{12}. We now turn to the empirical specification of our model.

3.7. Empirical Specification of the Model

In empirical specification of the model we have followed Nadiri and Rosen (1973) in specifying the equation in log-linear form.[8] Thus, (1) takes the following form:

$$RD_t = AY_t^{\alpha_1} w_t^{\alpha_2} q_t^{\alpha_3} PRD_t^{\alpha_4} (L/Y)_{t-1}^{\alpha_5} (K/Y)_{t-1}^{\alpha_6} e^{\lambda t} \qquad (12)$$

which yields the equation;

$$\ln RD_t = \alpha_0 + \alpha_1 \ln Y_t + \alpha_2 \ln w_t + \alpha_3 \ln q_t + \alpha_4 \ln PRD_t + \alpha_5 \ln (L/Y)_{t-1} + \alpha_6 \ln (K/Y)_{t-1} + \lambda t \qquad (13)$$

Recalling the assumption that our demand function is homogeneous of degree zero in w, q, and PRD we can express (13) as

$$\ln RD_t = \alpha_0 + \alpha_1 \ln Y_{t-1} + \beta_1 \ln (w/PRD)_t + \beta_2 \ln (q/PRD)_t + \alpha_5 \ln (L/Y)_{t-1} + \alpha_6 \ln (K/Y)_{t-1} + \lambda t \qquad (14)$$

When the unit cost of output is taken as the indicator of initial state of technology, (14) becomes

$$\ln RD_t = \alpha_0 + \alpha_1 \ln Y_t + \beta_1 \ln (w/PRD)_t + \beta_2 \ln (q/PRD)_t + \beta_3 \ln C_{t-1} + \lambda t \qquad (15)$$

At time t, lagged values of (L/Y), (K/Y), and C (unit cost of output) are taken as the indicators of state of technology in the two alternative specifications, respectively.

Equations (14) and (15) are estimated by the ordinary least squares regression procedure for eleven manufacturing industries in the United States. The results are reported in Chapter 5.

CHAPTER THREE: FOOTNOTES

1 As shown in the previous chapter, this is more or less the point made by Rosenberg against Schmookler's position.

2 See, for example, Edwin Mansfield, *"The Economics of Technological Change"*, New York, Norton, 1968; W. Comanor and F. Scherer, *"Patent Statistics as a Measure of Technical Change"*, Journal of Political Economy, May/June, 1969; and K. Pavitt and S. Wald, *"The Conditions for Success in Technological Innovation"*, Paris, OECD, 1971.

3 Each family of isoquants is equivalent to a unique cost function, see Diewart (1971). A unit isoquant is equivalent to a unit cost function, C/Y. If output measurement includes quality change, then product innovation increases output for given inputs. In that case, for both product and process innovations the same analytical framework can be used.

4 An alternative way to specify the initial state of technology is to include the stock of R&D at that time instead of KO/YO and LO/YO as is done by Nadiri (1979).

5 Nadiri assumed that price of R&D activity varied proportionally to user cost of capital and thus deleted it in the empirical specification of his model. This assumption does not seem realistic as we shall see in Chapter 4.

6 Professor Machlup (1962) has also expressed the idea of decreasing returns to inventive activity. Similarly, Binswanger's exposition of the scientific frontier as the limit where returns to R&D activity become zero also presupposes decreasing returns to R&D activity (1978).

7 It could be argued that the portion of R&D expenditures on basic research should be excluded from the present study but since they form a very small part of total R&D expenditures - around 4 percent (Mansfield, 1968, p. 13) - we have not attempted to deduct them from total expenditures.

8 Besides, Schmookler (1966), as well as Hayami and Ruttan (1971) have used the log-linear form for their empirical work.

CHAPTER FOUR

DATA AND SPECIFICATION OF THE VARIABLES

4.1. Introduction

This chapter is devoted to a discussion of data, their sources, and the specification of different variables used in the model as developed in the preceding chapter. The following is a list of the variables used:

RD - Real research and development expenditures;

Y - Real output;

w/PRD - Wage rate relative to the R&D price;

q/PRD - User cost of capital relative to the R&D price;

L/Y - Labour-output ratio;

K/Y - Capital-output ratio;

C - Unit cost of output;

t - Time.

The construction of these variables involves the use of additional variables, which will be defined as they are introducted in the following discussion. The capital stock and the user cost of capital variables entail a relatively lengthy discussion. Therefore, they are considered at the end of this chapter although, in certain cases, they will be referred to in earlier discussion, e.g., in the construction of the R&D price index and the unit cost of output variables.

All the data pertain to the 11 manufacturing industries in the United States selected for the present study. A discussion of the factors that were responsible for this selection along with the names of the selected industries is found in section 5.1. in Chapter Five.

4.2. Real Research and Development Expenditures

4.2.1. Nominal R&D Expenditures

The real R&D expenditures variable is constructed by deflating nominal R&D expenditures by the R&D price. The nominal R&D expenditure data are taken from two sources. Most of these data are taken from "*Research and Development in Industry*", an annual publication of the National Science Foundation (NSF).[1] However, data for the years 1953-1956, and 1976, were taken from the "*Statistical Abstract of the United States*" (henceforth the "*Statistical Abstract*").[2] Both total and private R&D expenditure data were used in this study. Total R&D expenditures include both public and private outlay on R&D in an industry. "*Research and Development in Industry*" defines total funds for research and development as the

> "operating expenses incurred by a company in the conduct of research and development in its own laboratories or other company-owned or operated facilities. Includes wages and salaries, materials and supply consumed, property and other taxes, maintenance and repairs, depreciation, and an appropriate share of overhead, but excludes capital expenditures".

Private R&D expenditures are defined as the

> "cost of the company-sponsored research and development performed within the company. Does not include company financed research and development contracted to outside organizations, such as research institutions, universities and colleges, or other non-profit organizations."[3]

In the private expenditure data series for the transportation equipments industry, the observation for the year 1974 was missing. This was filled by taking an average of the 1973 and 1975 values. Otherwise the years 1974-1976 could not have been included in the empirical estimation. And, since for this industry data for years 1953-1956 is unavailable, this would leave only 17 observations for the estimation.

4.2.2. R&D Price Indices

To deflate nominal R&D expenditures an R&D price series is needed. But no such series is available either in the literature or the published data. Nadiri (1979) used the user cost of capital to deflate the R&D stock on the assumption that the user cost of capital and the R&D price change proportionately. If that assumption is valid it would be safe to use the user cost of capital as a proxy for the R&D price and there would be only one relative factor price variable in the model, ie., the wage rate relative to the user cost of capital.

The assumption of user cost and the R&D price changing proportionately is not supported by the evidence on the cost structure of research and development activity. In this cost structure labour cost forms a significant proportion of total R&D cost. In most of the industries for the years for which a cost breakdown is available, labour cost forms more than 50% of the total R&D cost. This cost breakdown as given in the various publications of *"Research and Development in Industry"* for the years 1966-1967 and 1969-1975 is presented in Table 4.1. The R&D cost is broken down into the wage cost and the other cost which primarily consists of equipment (capital) cost. In view of this information a change in the wage cost will change the price of R&D activity in absence of any change in the user cost of capital.

Therefore, more appropriately, the R&D price should take both the wage rate and the relative user cost of capital into account. Since there is no physical unit in which R&D activity could be measured, only an index of the R&D price could be constructed. This index should be constructed as a weighted average of the wage and capital costs of R&D activity. The wage cost portion of total R&D cost consists of wage payments to R&D related personnel. So the wage rate of R&D personnel should be used in the construction of the R&D price index. But the wage rate of R&D personnel are not available.

Table 4.1

Percentage Distribution of R&D Costs, by Industry and Type of Cost, 1966-1967, and 1969-1975

Industry	Year																		Average	
	1966		1967		1969		1970		1971		1972		1973		1974		1975			
	w	o	w	o	w	o	w	o	w	o	w	o	w	o	w	o	w	o	w	o
Food and kindred products	57	43	57	43	59	41	60	40	59	41	57.7	42.3	56.7	43.3	59	41	60	40	58.4	41.6
Paper and allied products	59	41	59	41	56	44	55	45	51	49	49.7	50.3	50	50	57	43	58	42	55.0	45.0
Chemicals and allied products	56	44	56	44	57	43	56	44	56	44	55.3	44.7	55	45	55	45	55	45	55.7	44.3
Petroleum and coal products	54	46	54	46	52	48	48	52	49	51	47.6	52.4	47	53	46	54	48	52	49.5	50.5
Rubber and plastic products	53	47	53	47	47	53	52	48	49	51	49.2	50.8	48.8	51.2	51	49	50	50	50.3	49.7
Stone, clay, and glass products	59	41	58	42	59	41	58	42	57	43	54.5	45.5	54	46	57	43	57	43	57.0	43.0
Primary metals	53	47	55	45	57	43	58	42	59	41	57	43	57	43	53	47	53	47	55.7	44.3
Fabricated metal products	59	41	58	42	60	40	60	40	58	42	58	42	57	43	58	42	60	40	58.7	41.3
Machinery	52	48	53	47	56	44	57	43	56	44	56	44	56	44	54	46	53	47	54.7	45.3
Electrical and electronic equipment	48	52	47	53	48	52	48	52	48	52	47	53	46	54	48	52	49	51	47.7	52.3
Transportation equipment	54	46	55	45	58	42	58	42	59	41	56.6	43.4	56	44	-	-	57	43	56.7	43.3

w = percentage proportion of wage costs.

o = percentage proportion of other costs including capital costs.

However, data on the wage rate of production workers in each industry are readily available. Those data, along with the user cost of capital (see section 4 below) were used to construct an R&D price index according to the following formula:

$$PRD_i = A_i \times \frac{w_{it}}{w_{io}} + B_i \times \frac{q_{it}}{q_{io}} \qquad (1)$$

where PRD_{it} = R&D price index for the ith industry in year 't',

A_i = Average proportion of wage cost in total R&D cost for the ith industry as given in Table 4.1,

w_{it} = Wage rate of production workers for the ith industry in year 't',

w_{io} = Wage rate of production workers for the ith industry in the base year,

B_i = Average proportion of capital cost in total R&D cost (approximated by $1\text{-}A_i$) for the ith industry,

q_{it} = User cost of capital for the ith industry in year 't',

q_{io} = User cost of capital for the ith industry in the base year.

Since this R&D price index does not take the wage rate of R&D personnel into consideration, it was considered advisable to construct another R&D price index which explicitly takes account of that wage rate. Moreover, a second R&D price index makes it possible to compare the results for the two R&D price indices in order to test the robustness of the results with respect to alternative data specifications. The data on R&D personnel for different industries are available. If the data on the payroll of R&D personnel were also available it would be possible to construct a wage rate series for the R&D personnel for each industry. Unfortunately, these data are not available. *"Research and Development in Industry"* does give data on the cost per R&D scientist or engineer which could be used as a proxy for the wage rate of R&D personnel. However, these data are not available for the entire period of the study. The series pertaining to these data do not cover the years 1958-1962.

An alternative would be to use total R&D funds per R&D employee instead of total R&D cost to derive a proxy wage rate for R&D personnel. This proxy wage rate could be considered reasonably reliable since, as shown in Table 4.1, the proportions of the wage cost in different industries has remained fairly stable over time. Total rather than private R&D funds were used because the data on R&D personnel are not disaggregated into public and private R&D personnel. Using this procedure, w^*_{it} is derived as:

$$w^*_{it} = \frac{M_{it}}{N}$$

where w^*_{it} = Proxy wage rate for R&D personnel in year 't' for the ith industry,

M_{it} = Total R&D funds per R&D employee in year 't' for the ith industry,

N = Number of working hours in a year based on the assumption of 40 hours per week, 52 weeks per year.

w_{it} in equation (1) above was replaced by w^*_{it} to get the second R&D price index:

$$PRD^*_i = A_i \times \frac{w^*_{it}}{w_{io}} + B_i \times \frac{q_{it}}{q_{io}} \qquad (2)$$

In (2) w_{io} is retained as the deflator.[4] The reason is that for all the other data series 1948 was chosen as the base year and it was not possible to get a corresponding observation for R&D price since the relevant data are not available for 1948. In the subsequent discussion the R&D price index based on the wage rates of production workers will be referred to as R&D price index One while the price index based on the proxy wage rate for R&D personnel will be referred to as R&D price index Two.

4.3. Real Output

The real output was constructed by deflating value added in each industry by the corresponding wholesale price index (also called the producer's price index)[5]. The data on value added up to 1972 for the industries under study were taken from the *"Census of Manufacturing Industries, 1972"*.[6] For the remaining years, 1973-1976, the data were taken from the *"Statistical Abstract"*.

Data on the wholesale price index were taken from the *"Statistical Supplement to the Survey of Current*

Business". Most of these price data series correspond exactly to the industries under study. Nevertheless, for certain industries, a few remarks are in order. For the stone, clay, and glass products industry the wholesale price series for the nonmetallic mineral products (which includes, clay, concrete, and gypsum products) was used. For the primary metals and the fabricated metal products industries the wholesale price series for the metals and metal products industries was used because separate price series are not available. A separate wholesale price series for the electrical and electronic equipment industry was available, however, for the machinery industry (which excludes electrical machinery) the wholesale price series for the machinery and equipment industry was used. The latter series includes the wholesale price series for the electrical and electronic equipment industry. This was done because a wholesale price series for the machinery industry was not available.

All the wholesale price index series have 1967 as the base year. The base was shifted to 1948 to make all the wholesale price index series conform to all the other data series which have 1948 as the base year.

4.4. Wage Rate and Production Workers

The wage rate relative to the R&D price variable is based on the wage rates of production workers in each industry. Data on both the wage rate of production workers and the number of production workers in each industry are available in *"Employment and Earnings, United States"*.[7] Data for the last two years, 1975-1976, were taken from the *"Statistical Abstract"*.

For the construction of the labour-output ratio variable the data on production workers rather than total employment in an industry were used. This would be consistent with the wage rate data series which represents wage rates for production workers instead of wage rates for the entire labour force in an industry. The number of production workers in each industry was divided by the respective real output (as explained in section 4.3. above) to construct the labour-output ratio variable.

4.5. Unit Cost of Output

In the construction of the unit cost of output variable only costs associated with capital and labour were taken into account. The raw material costs could not be taken into account, primarily due to the data problems. The unit cost of output is thus defined as:

$$C_{it} = \frac{w_{it} \times L_{it} + q_{it} \times K_{it}}{Y_{it}} \qquad (3)$$

where C_{it} = Unit cost of output for the ith industry in year 't',

w_{it} = Wage rate of the production workers for the ith industry in year 't',

L_{it} = Production workers for the ith industry in year 't',

q_{it} = User cost of capital for the ith industry in year 't',

K_{it} = Real capital stock for the ith industry in year 't',

Y_{it} = Real output for the ith industry in year 't'.

4.6. Capital Stock and the User Cost of Capital

Data on the capital stock and user cost for each industry are not readily available. Aggregate capital stock figures for the economy as a whole or for different sectors of the economy are available in the literature but do not correspond to the level of disaggregation being considered in the present study.[8] The present analysis requires fixed rather than the total capital stock in each industry. The total capital stock includes circulating capital which is both prone to cyclical fluctuations and not relevant to innovative activity. Daniel Creamer in *"Capital Expansion and Capacity in Postwar Manufacturing"* (1961) has constructed fixed capital stock series for the different industries under consideration here but his estimates could not be utilized as they are available only up to 1959. Therefore, it was decided that the capital stock series should be constructed from the primary data on the gross investment in each industry using the following formula:

$$C_{it} = C_{it-1} + I_{it} - D_{it} \qquad (4)$$

where C_{it} = Nominal capital stock for the ith industry in year 't',

C_{it-1} = Nominal capital stock for the ith industry in year t-1.

I_{it} = Gross investment in the ith industry in year 't',

D_{it} = Amount of the capital depreciation in the ith industry in year 't'.

The capital stock of an industry (we shall use the term capital stock to refer to the fixed capital stock only) is comprised of both building and equipment capital stocks. In view of the widely divergent depreciation rates for building and equipment capital it is not advisable to use equation (4) to construct a single capital stock series for each industry. This procedure would imply the use of a single depreciation rate for both building and equipment. Hence for each industry building capital and equipment capital stock series were estimated separately and then added together to form the capital stock series for that industry.

The construction of the capital stock series as represented in equation (4) above requires a benchmark capital stock as well as data on depreciation and on gross investment for each industry.

4.6.1. Benchmark Capital Stock

Though Creamer's capital stock estimates could not be used as such, his estimates for the year 1948 could be used as the benchmark capital stocks for the purpose of constructing the capital stock series. Unfortunately Creamer's estimates are not divided into the building and the equipment capital stocks. To solve that problem his 1948 estimates were divided into building and equipment capital stocks according to the proportion of gross investment on the building capital and the equipment capital over a representative period. This was done on the assumption of a steady state capital stock which implies a) that the proportions of building and equipment capital stocks remain reasonably stable over a period of time; and b) that these proportions could be reasonably approximated by the proportions of gross building and equipment capital investment over the same period.

For this purpose, instead of taking only one year's gross building and equipment capital investment proportions, it was considered more appropriate to take an average of the proportions over several years. This reduces the possibility of an inaccurate division of the benchmark capital stock between building and equipment capital due to the volatility of gross building and equipment capital investment in a given year.

The percentage proportions of gross building and equipment capital investment as given by expenditures on construction, and equipment are presented in Table 4.2. The table reports these proportions for four years, 1947 and 1949-1951, spread over a period of five years, along with their averages. The data for expenditures on construction, and equipment for the year 1948 are unavailable. For the purpose of deriving the average proportions, the four closest possible observation points to the base year (1948) were chosen and presented in the table.

A brief look at Table 4.2 reveals that there is a certain variation in the proportions of expenditures on construction and equipment over time but it is not large. Normally it is around 10 percentage points except in the case of the petroleum and coal products and the transportation equipment industries. The petroleum and coal products industry is a peculiar case. The variation in the proportions of expenditures on the construction and the equipment is unidirectional in this industry. The proportion of construction expenditures decreases from 79.41% in 1947 to 51.13% in 1951. In addition, unlike all the other industries in which the proportions of expenditures on construction for the period under consideration are fairly stable around 30%, the proportion of expenditures on construction is very high and unstable in the petroleum

Table 4.2

Percentage Proportions of Expenditures on Construction, and Equipment in the Total Expenditures for Different Industries, 1947 and 1949-1951

Industry	1947		1949		1950		1951		Average	
	Bldg. Prop.	Equip. Prop.	Bldg. Prop.	Equip. Prop.	Bldg. Prop.	Equip. Prop.	Bldg. Prop.	Equip. Prop.	Bldg. Prop.	Equip. Prop.
Food and kindred products	33.72	66.28	36.09	63.91	33.22	66.68	35.20	64.80	34.58	65.42
Lumber and wood products	32.66	67.34	27.39	72.61	26.53	73.47	28.96	71.04	28.88	71.12
Paper and allied products	28.82	71.18	20.61	79.39	21.03	78.97	23.30	76.80	23.41	76.59
Chemicals and allied products	34.50	65.50	27.77	72.23	24.74	75.26	27.32	72.68	28.58	71.42
Petroleum and coal products	79.41	20.59	66.23	33.77	60.73	39.27	51.13	48.87	64.37	35.63
Rubber and plastic products	28.14	71.86	20.85	79.15	21.25	78.75	19.92	80.08	22.54	77.46
Stone, clay and glass products	36.62	63.38	26.94	73.06	24.54	75.46	29.33	70.67	29.36	70.64
Primary metals	35.92	64.08	28.25	71.75	25.30	74.70	35.85	64.15	31.33	68.67
Fabricated metal products	30.22	69.78	27.33	72.67	29.36	70.64	31.16	68.84	29.52	70.48
Machinery	32.34	67.66	30.07	69.93	25.76	74.24	35.07	64.93	30.81	69.19
Electrical and electrical equipment	26.52	73.48	28.71	71.29	25.61	74.39	37.25	62.75	29.52	70.48
Transportation equipment	28.03	71.97	21.04	78.96	22.34	77.66	38.23	61.77	27.41	72.59

and coal products industry. This implies that the distribution of capital between building capital and equipment capital in this industry does not conform to the other industries. The unidirectional change in the proportions of expenditures on construction and equipment also suggests that the composition of the capital stock in this industry was changing at that particular time. The division of the benchmark capital between building capital and equipment capital according to the average proportions of expenditures on construction and equipment would be reasonably uniform in all but the petroleum and coal products industry. In all the other industries, according to this procedure, the proportion of the building capital would vary from a low of 22.54% in the rubber and plastic products industry to a high of 34.58% in the food and kindred products industry. For the petroleum and coal products industry the proportion of building capital in the benchmark capital stock turns out to be 64.37%. Table 4.3 presents the benchmark capital stock taken from Creamer (1961) and its division between building capital and equipment capital stocks according to the methodology outlined above.

Table 4.3

Total, Building, and Equipment Capital Stock in Different Industries, 1948

Industry	Creamer's estimates of total capital stock (million$)	Building capital stock (million$)	Equipment capital stock (million$)
Food and kindred products	5338.00	1845.88	3492.12
Lumber and wood products	1599.00	461.79	1137.21
Paper and allied products	1900.00	444.79	1455.21
Chemicals and allied products	4100.00	1171.78	2928.22
Petroleum and coal products	9115.00	5867.32	3247.68
Rubber and plastic products	618.00	139.30	478.70
Stone, clay, and glass products	1462.00	429.24	1032.76
Primary metals	6052.00	1896.09	4155.91
Fabricated metal products	1713.00	505.68	1207.32
Machinery	3024.00	931.69	2092.31
Electrical and electronic equipment	1363.00	402.36	960.64
Transportation equipment	3152.00	863.96	2288.04

4.6.2. Gross, Building and Equipment Capital Investment

The data on construction and equipment expenditures are taken from two sources. From 1947 to 1962 the data are taken from the *"Statistical Abstract"*. The remaining data from 1963 to 1976 are taken from the *"Annual Survey of Manufacturers"* [9]. There were some difficulties with respect to these data. For example, the data for the years 1959-1960 are not available in the *"Statistical Abstract"*, as were the data for 1948 as was previously pointed out. The missing data for 1948 do not pose any problem since they are not required for the construction of the capital stock series. However, the capital stock series cannot be constructed without data for the years 1959-1960.

Fortunately the data on total expenditures on construction and equipment are available in the *"Census of Manufacturing Industries"* [10]. These expenditures were broken down between the construction and equipment categories according to the average proportions of the construction and the equipment expenditures, respectively for the years 1958 and 1961. These average proportions were calculated as:

$$A_i = \left(\frac{I^C_{i1958}}{I^T_{i1958}} + \frac{I^C_{i1961}}{I^T_{i1961}} \right) \div 2$$

and

$$B_i = \left(\frac{I^E_{i1958}}{I^T_{i1958}} + \frac{I^E_{i1961}}{I^T_{i1961}} \right) \div 2$$

where A_i and B_i are the calculated average proportions of the building and the equipment expenditures, respectively in the ith industry. I_i is the investment expenditures in the ith industry with postscripts T,C,E referring to total, construction, and equipment categories, respectively. Consequently;

$$I^C_{i1959} = A_i I^T_{i1959}$$

and

$$I^E_{i1959} = B_i I^T_{i1959}$$

for the year 1959. I^C_{i1960} and I^E_{i1960} are similarly calculated by using I^T_{i1960}.

4.6.3. Depreciation

The calculation of depreciation seems to be the most difficult problem in the construction of the capital stock series. Normally researchers have chosen the perpetual inventory formula to estimate the capital stock[11];

$$K_t = I_t + (1-\delta)\ K_{t-1} \qquad (5)$$

For the purpose of equation (5) the depreciation rate, 'δ' is derived from the useful life of the asset utilizing the concept of straight line depreciation. The depreciation rate is assumed to be the inverse of the useful life of an asset. Thus an asset having a useful life of 10 years would have a depreciation rate of 0.1. More precisely, the depreciation proportion is used as the depreciation rate. For example, in the above example 0.1 is in fact the depreciation proportion for an asset having a useful life of 10 years.

Our contention is that the above-mentioned procedure of using the depreciation proportion as the depreciation rate in the perpetual inventory formula given by equation (5) is conceptually faulty. This is easily explained in the following figure.

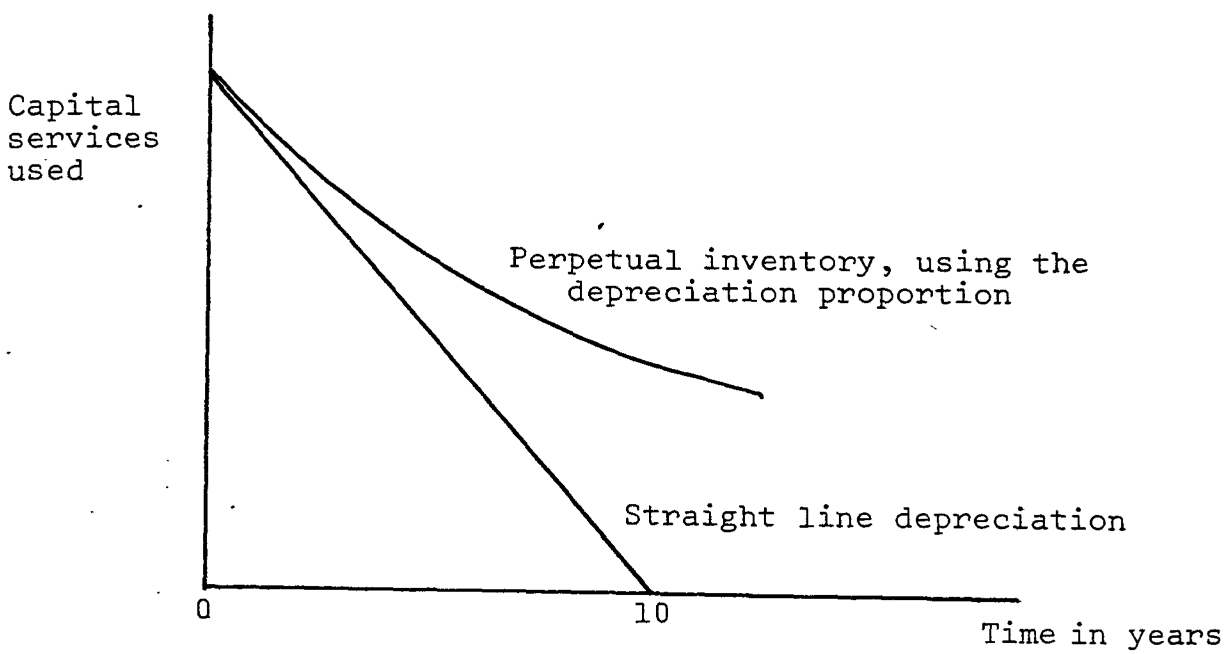

Figure 4.I

Capital Services Under Perpetual Inventory and Straight Line Depreciation Formulae

In Figure 4.I it is very clear that under the straight line depreciation the services of an asset cited in the foregoing example would terminate at the end of the tenth year whereas under the perpetual inventory formula a significant amount of services would still remain in use. In other words, the depreciation rate under the straight line depreciation formula is higher. In fact, it depends on the amount of depreciation. This can be further clarified with the help of the same example elaborated in Table 4.4. It is clearly seen in Table 4.4 that a $100 asset which was supposed to terminate its services at the end of year 10 under the assumption of straight line depreciation still retains its services worth $34.87 when the depreciation proportion is used as the depreciation rate in the perpetual inventory formula[12].

The foregoing analysis indicates that the depreciation rate in the perpetual inventory formula does not have a sound conceptual basis. There is no valid reason, except convenience, to use the depreciation proportion as the depreciation rate in the perpetual inventory formula.

In what follows we have used the straight line depreciation method to construct the capital stock series, which would be called the straight line depreciation capital formula. The straight line depreciation concept is used to arrive at the depreciation proportions. The

Table 4.4

Capital Services and the Depreciation Rates under Perpetual Inventory and Straight Line Depreciation Formulae

Year	Capital Services used ($)		Depreciation Rate (percent)	
	Perpetual inventory formulae	Straight line formulae	Perpetual inventory formulae	Straight line formulae
1	100.00	100.00	10	10
2	90.00	90.00	10	11.11
3	81.00	80.00	10	12.50
4	72.90	70.00	10	14.28
5	65.61	60.00	10	16.67
6	59.05	50.00	10	20.00
7	53.14	40.00	10	25.00
8	47.83	30.00	10	33.33
9	43.05	20.00	10	50.00
10	38.74	10.00	10	100.00
11	34.87	00.00	10	-

depreciation rate is endogenous to the system. It is determined by the amount of depreciation divided by the capital stock on which it was applicable.

The depreciation proportions for the industries under consideration require information about the useful lives of different assets in those industries. This information is obtained from the *"Regulations and Rev. Proc. 72.10"* where for each class of assets an "asset guideline period" is given.[13] Building capital is treated uniformally irrespective of the industry and there is a fixed "asset guideline period" of 45 years for this class of assets. The depreciation proportion would be the reciprocal of the "asset guideline period" (AGP). The other classes of assets in each industry do not exactly correspond to a two-digit classification of industries which is the level of aggregation used in the present study. For each two-digit industry, there are normally three sub-classes of assets for which AGP is specified. The AGP ranges from six to twenty years across industries though the range is not that large within each industry. For each industry an average of the asset guideline periods is taken as the basis of the depreciation proportion which shall be called the average asset guideline period (AAGP) for that industry.[14] The depreciation proportion for equipment capital in each of the industries is the reciprocal of the AAGP.

4.6.4. Straight line Depreciation Capital Formula and the Estimation of Capital Stock

The following formula is developed for the straight line depreciation capital:

$$C_t = C_{t-1} + I_t - \left[\sum_{g=1}^{t-1} \rho I_{t-g} + \rho C_o \right] \qquad (6)$$

when $g=\ell$; $I_{t-g}=0$

and if $t=\ell$; $C_o=0$

where C_t = Capital stock in year 't',

C_{t-1} = Capital stock in year t-1,

C_o = Benchmark capital stock,

I_t = Gross investment in year 't',

ρ = Depreciation proportion,

ℓ = Useful life of the asset according to AGP or AAGP.

The term in the parenthesis yields the amount of depreciation. The first term in the parenthesis is to calculate the amount of depreciation on the new capital goods while the second term is for the accounting of depreciation on the benchmark capital stock. The two restrictions for the depreciation term in the parenthesis are needed to terminate the accounting of depreciation once the useful life of the asset is over.

The formula is not yet ready for empirical application. It still has to take into account the prices of capital goods. Information on gross investment is in terms of current dollars while the benchmark and last year's capital stock are not expressed in current dollars.[15] The formula in (6) needs to be revised as follows:

$$C_t = C_{t-1}\left(\frac{P_t}{P_{t-1}}\right) + I_t - \left[\sum_{g=1}^{t-1} \rho I_{t-g}\left(\frac{P_t}{P_{t-g}}\right) + \rho C_o\left(\frac{P_t}{P_o}\right)\right] \quad (7)$$

$$\text{when } g=\ell;\ I_{t-g}=0$$
$$\text{and if } t=\ell;\ C_o=0$$

where all the terms except the price terms are the same as in (6). Equation (7) gives current dollar capital stock. The price terms represent the price of capital goods with subscripts referring to the time period. The capital goods price indices as available in the *"Survey of Current Business"* are used.[16]

It has already been noted that there is a considerable difference in the depreciation proportions for building capital and equipment capital. Therefore, the building capital and equipment capital series were constructed separately for each industry. For this the following two formulae were used:

$$C_t^B = C_{t-1}^B \left(\frac{P_t^B}{P_{t-1}^B}\right) + I_t^B - \left[\sum_{g=1}^{t-1} \rho^B I_{t-g}^B \left(\frac{P_t^B}{P_{t-g}^B}\right) + \rho^B C_o^B \left(\frac{P_t^B}{P_o^B}\right)\right] \quad (8)$$

when $g=\ell$; $I_{t-g}^B=0$

and if $t=\ell$; $C_o^B=0$

$$C_t^E = C_{t-1}^E \left(\frac{P_t^E}{P_{t-1}^E}\right) + I_t^E - \left[\sum_{g=1}^{t-1} \rho^E I_{t-g}^E \left(\frac{P_t^E}{P_{t-g}^E}\right) + \rho^E C_o^E \left(\frac{P_t^E}{P_o^E}\right)\right] \quad (9)$$

when $g=\ell$; $I_{t-g}^E=0$

and if $t=\ell$; $C_o^E=0$

for building and equipment capital, respectively. The superscripts B and E refer to those two categories. The real capital stock is derived by dividing the nominal capital stock by the price index. Thus if K_t^B and K_t^E denote the real building and the real equipment capital stocks, respectively in year 't' then;

$$K_t^B = \frac{C_t^B}{P_t^B} \quad (10)$$

and

$$K_t^E = \frac{C_t^E}{P_t^E} \quad (11)$$

The total capital stock in year 't', K_t, is the sum of the building and the equipment capital stocks. So

$$K^t = K_t^B + K_t^E \quad (12)$$

4.6.5. User Cost of Capital

The user cost of capital is the weighted average of the user costs of building and equipment capital. For their respective user costs the depreciation rates for the building and the equipment capital are required. These depreciation rates are defined as:

$$\delta_t^B = \frac{\text{Amount of building capital depreciation in year 't'}}{\text{Building capital stock in year t-1}} \qquad (13)$$

$$\delta_t^E = \frac{\text{Amount of equipment capital depreciation in year 't'}}{\text{Equipment capital stock in year t-1}} \qquad (14)$$

where δ_t^B and δ_t^E are the building and the equipment capital depreciation rates, respectively in year 't'. The amounts of depreciation for the purpose of (13) and (14) are taken from the depreciation terms in (8) and (9), and so are the previous year's capital stock estimates (the denominators in (13) and (14)). The user costs for the two capital categories are;[17]

$$q_t^B = \left(\delta_t^B + r_t - \frac{\dot{P}_t^B}{P_t^B} \right) P_t^B \qquad (15)$$

and

$$q_t^E = \left(\delta_t^E + r_t - \frac{\dot{P}_t^E}{P_t^E} \right) P_t^E \qquad (16)$$

where q_t^B and q_t^E are the user cost of building and equipment capital, respectively in year 't'. All the variables except 'r' have been defined earlier. A dot over P represents the first derivative of P with respect to time. The symbol 'r' represents the interest rate. We use the interest rate on the long term United States government bonds.[18] The user cost of total capital is the weighted average of the user costs of building and equipment capital as given in (15) and (16). The ratios of real building capital and real equipment capital to total capital are used as the weights. Therefore, the user cost of capital in year 't' is:

$$q_t = \frac{K_t^E \times q_t^B + K_t^E \times q_t^E}{K_t^B + K_t^E} \qquad (17)$$

The capital-output ratio variable for each industry is derived by dividing the capital stock of that industry by its real output. The estimated capital stock, the depreciation rate and the user cost of capital series are reported in the appendix.[19]

In this chapter we have discussed the construction of different variables which are used in the subsequent empirical application. There was a detailed discussion on the methodology for the construction of capital stock series. The next two chapters are devoted to the results of the empirical estimation.

CHAPTER FOUR: FOOTNOTES

1 National Science Foundation, Washington, D.C. This publication is the original source of all the data on Research and Development (R&D) expenditures.

2 A yearly publication of the U.S. Department of Commerce, Bureau of The Census, Washington, D.C. NSF, however, is the primary source of data on Research and Development for this publication. Therefore, the data are consistent.

3 For the years for which data are available (1965-1975) company financed research and development contracted to outside organizations was negligible for most of the industries. The industries having the largest proportion were the food and kindred products, chemicals and allied products, petroleum and coal products, and stone, clay, and glass products. In these industries company financed research and development contracted to outside organizations was, on average, around 4% of the research and development conducted within the company.

4 Since there is no reason to assume that $w^*_{oi} = w_{oi}$, the use of w_{oi} in the second price index introduces a distortion. If $w_{oi} = \theta w^*_{oi}$ then the factor θ would represent that distortion. However, since θ is a constant, it should not affect the results very much. On the other hand, some other year could be used as the base year for the relative factor price variables like 1957 in which case w^*_{oi} would be available. We tried 1957 as base year but it does not seem to make much difference in the results.

5 There is an inconsistency in using the producer's price index to deflate value added, since the producer's price includes the value of materials;

Nominal value added = value of output - value of materials
Real value added = real output - real value of materials.

$$\text{Real value added} = \frac{\text{value of output}}{\text{producer's price}} - \frac{\text{value of materials}}{\text{material's price}}$$

$$\text{Real value added} = \frac{\text{value of output}}{\text{producer's price}} - \frac{\text{value of materials}}{\text{producer's price}} + \frac{\text{value of materials}}{\text{producer's price}} - \frac{\text{value of materials}}{\text{material's price}}$$

$$\text{Real value added} = \frac{\text{nominal value added}}{\text{producer's price}} + \frac{\text{value of materials}}{\text{producer's price}} - \frac{\text{value of materials}}{\text{material's price}}$$

$$\text{Real value added} = \frac{\text{nominal value added}}{\text{producer's price}} + \frac{\text{value of materials}}{\text{material's price}} \left(\frac{\text{material's price}}{\text{producer's price}} - 1 \right) \qquad (*)$$

The second term on the right hand side of (*) represents an error. This will introduce a distortion in the magnitude of real value added variable. In the absence of other data which would allow the computation of a better price index, the analysis retains the deficiency introduced by the error term above.

6 U.S. Department of Commerce, Bureau of the Census, Washington, D.C.

7 U.S. Department of Labour, Bureau of Labour Statistics, Washington, D.C.

8 In particular the present study required these estimates up to 1976.

9 U.S. Department of Commerce, Bureau of the Census, Washington, D.C.

10 *Ibid.*

11 See, for example, Bert G. Hickman's *"Investment Demand and U.S. Economic Growth"*, The Brooking Institution, Washington, D.C., 1965; or a recent study by M.I. Nadiri, *"Contribution and Determinants of Research and Development Expenditures in the U.S. Manufacturing Industries"*, working paper #79-16, New York University, Department of Economics, N.Y.

12 It is interesting to note that after theoretically using the lower depreciation rate (which is implied by the use of depreciation proportion as the depreciation rate) Hickman (1965, p. 225) goes on to double that depreciation rate for manufacturing industries, calling it a double rate declining-balance formula, indicating that it is supported by the observations in the market for second hand equipment of certain types while commenting that "unfortunately, similar data are lacking for industrial or commercial plant" (p. 224).

13 These asset guidelines are available in the *"1977 U.S. Master Tax Guide"*, Commerce Clearing House, Chicago, 1976.

14 For example, in the food and kindred products industry there are two asset classes having an AGP of 14 and 12 years, respectively. Therefore, the AAGP for this industry is 13 years.

15 At this point the conceptual difficulties with regard to the aggregation of capital should be acknowledged. The difficulty of aggregating capital into a theoretically impeccable measure has frequently been pointed out in the literature. However, in *"Capital and Time"*, Hicks' has argued that measures of capital generally employed in the empirical analyses are meaningful. The concept of capital used in the present study is the volume concept of capital (where capital goods own prices are used to arrive at the real capital stock) which he shows to be associated with his backward-looking measure of capital.

16 *"Survey of Current Business"*, July, 1976, p. 61; U.S. Department of Commerce, Washington, D.C. The base was shifted from 1972 to 1948.

17 The user cost formulae are derived from Dale W. Jorgenson's *"Capital Theory and Investment Behaviour"*, American Economic Review, May, 1963. His formula is modified to the extent that the tax parameters are not included in the present formulation, and the depreciation rate is a variable instead of a constant. It should be pointed out that Jorgenson's formula is based on the perpetual inventory formula of capital stock. Under straight line depreciation capital stock concept, the user cost formula becomes quite unmanageable. Therefore, Jorgenson's formula with the above mentioned modifications were used as an approximation.

18 These data are taken from the *"Banking and Monetary Statistics, 1941-1970"*, and the *"Annual Statistical Digest"*, Board of Governors of the Federal Reserve System, Washington, D.C.

19 The primary data are not reported in this study. However, they are readily available on request. The capital stock and other estimated data reported in the appendix include the lumber and wood products industry although it is not included in the subsequent empirical estimation of the model due to the lack of data on research and development expenditures.

CHAPTER FIVE

RESULTS OF THE EMPIRICAL ESTIMATION

5.1. Introduction

The model of induced technological change as presented in Chapter Three is tested for eleven manufacturing industries in the United States. The estimation could be carried out for any level of aggregation, e.g., for the entire manufacturing sector or for the consumer goods and the durable goods industries separately. However, neither of the preceding aggregation levels allow for the individual characteristics of the industries included therein. The two-digit standard industrial classification (SIC) is especially suitable for it takes into account the individual features of each industry without imposing data constraints. Table 5.1 lists the industries included in the analysis along with their SIC numbers. The choice of these industries was dictated by the availability of data, particularly data on R&D expenditures. Industries other than these, with the exception of the instruments and related products industry, could not be included in the analysis since R&D expenditure data for them are not published. The instruments and

Table 5.1

SIC Code and the Names of the Industries Included in the Analysis

SIC code	Industry
20	Food and kindred products
26	Paper and allied products
28	Chemicals and allied products
29	Petroleum and coal products
30	Rubber and plastic products
32	Stone, clay, and glass products
33	Primary metals
34	Fabricated metal products
35	Machinery except electrical
36	Electrical and electronic equipments
37	Transportation equipments

related products industry could not be included for a data limitation of a different kind. For this industry it was not possible to construct the capital stock series (see Chapter Four) because the required benchmark capital stock is not available in Daniel Creamer's (1961) work.

The choice of time period was also based on data considerations. The study covers the period from 1953 to 1976; 1953 being the first year for which R&D expenditures are reported. More comprehensive data on R&D expenditures appear from 1957 onward. That year marks the first time R&D data was disaggregated into private and public expenditures. From 1953 to 1956, we could get only total outlay on R&D. Our analysis is couched in terms of private expenditures on R&D, therefore, for most of the industries the empirical analysis begins with 1957. There are two exceptions; namely the paper and allied products, and the stone, clay and glass products industries which include the years 1953 to 1956 as well. For these industries we used total expenditures on R&D to carry out the analysis because of the following deficiencies in the data on private R&D expenditures.

For the paper and allied products industry, there are gaps in the published data. Data for years 1960, 1961, 1966, and 1968-1971 are not published. Moreover, the data series is discontinued after 1973. For the stone, clay and glass products industry, the data are reported for only 15 years, ie., from 1961 to 1975. This limits the degrees of freedom available in the regression analysis, so it was considered more appropriate to carry out the analysis in terms of total expenditures on R&D.

The decision to carry out the analysis in terms of total expenditures on R&D is supported by the fact that in these industries the proportion of public expenditures on R&D is very small. For the years for which the data on both public and private R&D expenditures are reported, public expenditures on average accounted for only 0.6 and 2.85% of the total expenditures in the paper and allied products, and stone, clay and glass products industries, respectively. Therefore, the margin of inaccuracy as a result of using total rather than private expenditures on R&D should be small and the results can be taken as reasonably reliable.

In two other industries (food and kindred products, and petroleum and coal products), the published data series on private R&D expenditures end with the year 1975, while in the case of the rubber and plastic products industry, the same series end at 1973. Furthermore, the total R&D expenditures series for the rubber and plastic products industry begins in 1957 instead of 1953. In these three industries the number of observations was restricted to be less than twenty when the analysis is carried out for private R&D expenditures. Though it does not impose a serious constraint on the degrees of freedom, the results were also estimated for total expenditures on R&D (which increases the number of observations from 19 to 24 for the food and kindred products, and petroleum and coal products industries, and 17 to 20 for rubber and plastic products industry) for the sake of comparison.

The regression equations were estimated using four different combinations of data. In the previous chapter, we constructed two alternative series for the R&D price index for each industry. Index One was constructed by using data on the wage rates for the production workers in that industry. For index Two, the proxy wage rates for R&D personnel in that industry were utilized. In Chapter Three, two sets of variables were specified to identify the initial state of technology. One of these sets contains the capital- and labour-output ratios while the alternative specification uses only the unit cost of output.

In this way, each equation for the demand for R&D expenditure has four possible variants, combining two different specifications of the initial state of technology with two different measures of the R&D price index. For each industry, except stone, clay and glass products, these four variants were estimated. For the stone, clay and glass products industry, unavailability of data on R&D personnel left no choice but to carry out the estimation with only R&D price index One. Therefore, only two variants, one pertaining to each alternative specification of the initial state of technology, could be estimated. Thus the total number of estimated equations for 11 industries is 42.

5.2. The Results

5.2.1. Quality of the Results

Generally the quality of the estimated regression equations as indicated by the R^2 statistic is very good.

For the sake of clarity of presentation, and ease of comprehension the industries were divided into two sets: High and Low R&D industries. Detailed discussion of the underlying characteristics of the industries on which this division is based is presented in section 5.3. The R^2 statistic is greater than 0.9 in 36 out of 42 estimated equations and in 33 of the 36 cases it is greater than 0.96. All of the six cases where it is less than 0.9 correspond to Low R&D industries.

The Durbin-Watson (D-W) statistic in the preliminary results indicated a need for an adjustment for autocorrelation. In 13 out of 42 estimated equations the hypothesis of the presence of autocorrelation was rejected at one percent significance level. For the remaining 29 cases, the Cochrane-Orcutt (CORC) iterative technique to adjust for autocorrelation was used.

More precisely, in four out of 29 equations, the hypothesis of the presence of autocorrelation was accepted at one percent level of significance. In each of these four cases, the Cochrane-Orcutt iterative technique successfully removed the autocorrelation.

In the remaining 25 of the 29 equations, the D-W statistic fell in the inconclusive range. In these cases the hypothesis of the presence of autocorrelation could neither be accepted nor rejected at one percent significance level. When the adjustment for autocorrelation was carried out, it was successful in 15 out of these 25 cases. This means that while in 15 cases the hypothesis of the presence of autocorrelation was rejected at one percent level of significance, it could not be rejected for the other 10 cases. The D-W statistic still fell in the inconclusive range.

Consequently we have adhered to the following procedures to determine which estimated equations would be included in the subsequent discussion of the results:

(a) Those equations where no autocorrelation was detected in the preliminary results pose no problem. For them no Cochrane-Orcutt adjustment was necessary.

(b) Those four cases where autocorrelation was detected also do not pose any problem since in each of the four cases correction for autocorrelation was successful. Therefore, the post-autocorrelation adjustment results are the basis for the subsequent discussion. Both pre- and post-autocorrelation adjustment estimates are reported in the tables for the information of the reader.

(c) In the cases where the D-W statistic in the preliminary results fell in the inconclusive range, a choice had to be made as to which set of estimated equations should form the basis of discussion. The choice was easier in the cases where post-autocorrelation-adjustment results rejected the hypothesis of the presence of autocorrelation. In these cases post-adjustment results form the basis of further discussion. Both pre- and post-autocorrelation-adjustment equations are, however, reported in the tables containing the results.

(d) The choice was not easy in those cases where both the pre- and post-autocorrelation-adjustment D-w statistic fell in the inconclusive region. Since there is no reason to prefer the post-adjustment results, it was considered more appropriate to base the later discussion on pre-adjustment results. Again, both estimates are reported in the tables for the reader's interest. For the sake of convenience, all the equations that form the basis of the discussion are marked with asterisks.

Detailed discussion of the results for individual industries follows brief comments on the significance of the coefficients of different variables.

5.2.2. Output of the Industry

The significant coefficients for each of the four variants for all the industries are presented in the tables 5.2 to 5.5. Those tables report only the signs of the coefficients, ie., positive or negative. The blank spaces indicate insignificant coefficients. The confidence interval for the purpose of these tables is 90% in a two-tailed test though most of the coefficients would remain significant even if the confidence interval were raised to 95%.

Table 5.2

Signs of the Significant Coefficients when Capital- and Labour-output Ratios are used as the State of Technology Variables, along with R&D Price Index One

Industry	Independent Variables					
	Y	w/PRD	q/PRD	$(K/Y)_{-1}$	$(L/Y)_{-1}$	t
Transportation equipment	(+)			(+)	(-)	
Electrical & electronic equipment	(+)	(+)		(+)	(-)	
Machinery	(+)	(+)	(+)	(+)	(-)	(-)
Chemicals & allied products		(+)				
Food & kindred products		(+)			(-)	
Rubber & plastic products	(-)			(+)	(+)	
Paper & allied products	(+)					
Primary metals	(+)		(-)	(+)	(-)	(-)
Petroleum & coal products		(+)			(-)	
Fabricated metal products		(+)			(-)	
Stone, clay & glass products		(+)				

Table 5.3

Signs of the Significant Coefficients when Capital- and Labour-output Ratios are used as the State of Technology Variables, along with R&D Price Index Two

	Independent Variables					
Industry	Y	w/PRD	q/PRD	$(K/Y)_{-1}$	$(L/Y)_{-1}$	t
Transportation equipment		(+)	(+)	(+)	(-)	
Electrical & electronic equipment	(+)	(+)	(+)	(+)	(-)	(+)
Machinery	(+)	(+)		(+)	(-)	(-)
Chemical & allied products	(+)	(+)				
Food & kindred products	(+)			(+)	(-)	
Rubber & plastic products	(-)	(+)		(+)	(+)	
Paper & allied products		(+)		(+)	(-)	
Primary metals			(+)	(+)	(-)	
Petroleum & coal products		(+)			(-)	
Fabricated metal products		(+)				

Table 5.4

Signs of the Significant Coefficients when Unit Cost is used as the State of Technology Variable, along with R&D Price Index One

Industry	Independent Variables				
	Y	w/PRD	q/PRD	C_{-1}	t
Transportation equipment	(+)	(+)			
Electrical & electronic equipment	(+)	(+)			
Machinery	(+)	(+)	(+)	(+)	(-)
Chemicals & allied products		(+)			
Food & kindred products	(+)	(+)		(-)	
Rubber & plastic products		(+)	(+)		(+)
Paper & allied products	(+)		(-)		
Primary metals	(+)				
Petroleum & coal products	(+)	(+)			
Fabricated metal products	(+)	(+)			
Stone, clay & glass products		(+)		(+)	

Table 5.5

Signs of the Significant Coefficients when Unit Cost is used as the State of Technology Variable, along with R&D Price Index Two

Industry	Independent Variables				
	Y	w/PRD	q/PRD	C_{-1}	t
Transportation equipment	(+)	(+)			
Electrical & electronic equipment	(+)	(+)	(-)		
Machinery	(+)	(+)	(-)	(+)	(-)
Chemicals & allied products	(+)	(+)			(-)
Food & kindred products	(+)	(+)		(-)	
Rubber & plastic products		(+)			
Paper & allied products		(+)			
Primary metals				(+)	
Petroleum & coal products	(+)	(+)		(+)	
Fabricated metal products		(+)	(-)		

Tables 5.2 to 5.5 show that the coefficient of the output variable is significant in 25 out of the 42 estimated equations. The sign of this coefficient was expected to be positive. It is positive in all but two equations pertaining to the rubber and plastic products industry. Most of the industries in which the output coefficients are significant belong to the High R&D industries.

In Chapter Three, section 3.3., the effect of the output of an industry was discussed in the formal model. It was argued that R&D expenditures reduce the unit cost of output. Therefore, a decision to undertake, let us say, 'X' amount of R&D expenditure, given everything else unchanged, may become feasible only if the output of the industry were, let us say, higher than 'Y', otherwise not. This argument was further elaborated in section 3.6. (also see Figure 3.V.). Equation (6) in Chapter Three gives;

$$\frac{dRD}{dy} = - \frac{\partial^2 C/\partial RD \partial y}{\partial^2 C/\partial RD^2}$$

whose positive sign was conditioned by two assumptions. First, $\partial^2 C/\partial RD^2 > 0$; showing decreasing returns to R&D activity (Evenson-Kislev, 1975). Second, $\partial^2 C/\partial RD \partial y < 0$; which means that for a given output level, an increase in R&D expenditures causes marginal cost ($\partial C/\partial y$) to decrease.

The empirical evidence supports these assumptions, dRd/dy is positive in all the cases except in the rubber and plastic products industry. This industry also has certain other peculiar results which are discussed, along with the output coefficient, in section 5.5.

5.2.3. Relative Factor Prices

There are two relative factor price variables: wage rate relative to the price of R&D (henceforth relative wage rate), and user cost of capital relative to the price of R&D (henceforth relative user cost). The relative wage rate coefficient, a look at tables 5.2 - 5.5 reveals, is significant in 33 of the estimated equations; quite a few more cases than the output coefficient. The relative user cost coefficient, on the other hand, is significant in only 11 of the estimated equations.

It should be recalled from Chapter Three (section 3.6.) that it was not possible to put any restrictions on the signs of relative factor price variables. There, in a detailed discussion, it was argued that Hicks' second assertion (as explained in Chapter Two) was theoretically plausible. All along in that discussion it was presumed that the effect of a higher relative factor price would be a higher rate of innovative activity (higher R&D expenditures). However, it was also shown that this may not be true at all times (see section 3.6.). Therefore, the signs of dRD/d(w/PRD) and dRD/d(q/PRD) could not be determined on a priori grounds.

Nevertheless it is interesting to note that the coefficient of the relative wage rate is positive in all the cases. This evidence indicates that an increase in the wage rate was a spur to innovative activity - à la Hicks - for the time period under study.

A similar consistency in the sign of the relative user cost coefficient is not observed. It is positive in six and negative in five of the 11 estimated equations where it is significant. Moreover, it shows an erratic behaviour since its sign differs in the same industry under the four alternative specifications. For example, in the primary metals industry it assumes a positive sign when the R&D price index Two is used whereas under the R&D price index One its sign is negative. This is shown in Tables 5.2 and 5.3. The same happens in the case of the machinery industry as shown in Tables 5.4 and 5.5. Again, in the electrical and electronic equipment industry it exhibits the same behaviour when the state of technology specifications is altered. This can be seen by looking at Tables 5.3 and 5.5.

In view of this, it is hard to form any definitive impression about the effect of the relative user cost variable. Based on the empirical evidence, it could be said that the relative wage rate is much more important than the relative user cost in determining R&D expenditures.

5.2.4. Initial State of Technology

There are two alternative specifications for the initial state of technology. One of these specifications has two variables, namely the capital- and labour-output ratios. The other uses the unit cost of output. Each specification is used in one-half of the estimated equations. Thus there are 21 estimated equations for each specification of the state of technology.

Again referring back to Tables 5.2 - 5.6, it is found that when the capital- and labour-output ratios specification is used, coefficients for both of them are significant in 12 out of the 21 estimated equations. In another four of the remaining nine equations the labour-output ratio coefficient alone is significant. In none of the estimated equations is the capital-output ratio coefficient alone significant.

As far as the consistency of the signs of these coefficients is concerned, a very clear pattern emerges. With the exception of the rubber and plastic products industry, the sign of capital-output ratio coefficient is positive while that of labour-output ratio coefficient is negative.

The discussion of the state of technology (see section 3.4. in Chapter Three) was couched in terms of 'mature' and 'rudimentary' technology. Technological change in an industry necessarily reduces at least one of the input requirements for a unit output. As more and more technological change takes place, the isoquant for a unit output moves steadily closer to the origin and consequently at least one of the inputs for a unit output decreases. Therefore, when per unit factor inputs are large, there is more scope for potential decrease in them. Technology of an industry was defined according to whether dRD/d(LO/YO) and dRD/d(KO/YO) are positive or negative.

If their signs are negative the discussion with respect to equation (7) in Chapter Three designated them as 'mature' technologies. This is because it implies a higher marginal cost-saving when the factor intensities are larger. On the other hand, technology was defined to be 'rudimentary' when the signs of dRD/d(LO/YO) and dRD/d(KO/YO) are positive for symmetrical reasons.

It is not possible to classify any industry, save rubber and plastic products, as either a 'mature' or a 'rudimentary' technology industry according to these definitions. Only in the rubber and plastic products industry do both the coefficients have positive signs which, according to our definition, makes it a 'rudimentary' technology industry. Not withstanding this inability to classify most of the industries in either of the above categories, the evidence indicates that the state of technology has a bearing on the level of R&D expenditures in various industries (see Figure 3.II). To substantiate this argument further, we looked at the absolute value of the coefficients of the capital- and labour-output ratio. Pending later discussion, it should suffice here to note that again a clear pattern emerged where, invariably, the coefficient of the capital-output ratio is almost twice the size of the coefficient of labour-output ratio in terms of absolute value.

Let us now analyze the results when unit cost is used as the alternative specification for the state of technology. It could prove to be useful in classifying the industries as 'mature' or 'rudimentary' technology industries in the sense that we do not have the constraint of two coefficients having to have the same sign to do that. Only one coefficient, that of the unit cost, could be used for that purpose.

Unfortunately the results are not very strong when the unit cost specification of the state of technology is used. It is significant in only seven of the 21 estimated equations. Out of these seven the sign is positive in five and negative in two cases. The latter two cases where it has negative sign both pertain to the food and kindred products industry (see Tables 5.2 - 5.5). Furthermore, in only one other industry,i.e., the machinery industry, is the coefficient significant for both the R&D price specifications. While in the remaining three of the seven cases it is significant for only one of the R&D price specifications.

Referring back to Chapter Three (section 3.4.) once again, it was explained that technological change shifts the average cost curve of the firm downwards. In other words, as technological change takes place the unit cost of output successively decreases. The higher the initial unit cost, the more is the potential room for improvement in the technology (see equation (10) in Chapter Three). If $dRD/dC_o > 0$, the industry is defined to have 'rudimentary' technology because cost saving is higher the larger is the unit cost. The 'mature' technology industry is defined when $dRD/dC_o < 0$ as would follow for a symmetric reason.

Consequently the food and kindred products industry would qualify as a 'mature' technology industry, while the machinery industry would seem to have 'rudimentary' technology according to the empirical evidence. For the remaining three of the seven cases, where the coefficient of unit cost was significant but only for one of the R&D price specifications, we resist the temptation to label them.

Since the results, in general, are not very strong for the unit cost specification, in the subsequent discussion any inference on the state of technology is based on a simultaneous consideration of both of the state of technology specifications.

5.2.5. State of Knowledge

Results with respect to the state of knowledge variable, 't', are not very strong either; indeed they are the weakest of all the variables. Tables 5.2 - 5.5 show that the state of knowledge coefficient is significant in only eight out of 42 estimated equations. Out of those eight, its sign is positive in two while negative in the remaining six cases. At first this caused a little surprise since its sign was expected to be positive. A second look at the results revealed that four out of the six cases where its sign is negative belong to the same industry, ie., the machinery industry where its sign is consistently negative in all the four variants of specification. The remaining four of the eight cases where this coefficient is significant are scattered about and do not reveal any consistent pattern.

The justification for a positive sign for the state of knowledge coefficient was presented in Chapter Three (section 3.5). It was argued that as the state of knowledge changes over time, the same level of R&D expenditures would cause a greater unit cost reduction. This means $\partial^2 C/\partial RD \partial t$ is negative and, therefore, $dRD/dt > 0$ (see equation (12) in Chapter Three).

Another way of explaining this is to say that with the passage of time the scientific frontier (as explained in Chapter Two) shifts inward and pulls the IPC with it.

A particular IPC would then move closer to the origin as time goes on. An attempt was made to show that the inward movement of the scientific frontier represents the supply side of innovative activity. It is a function of basic research. Therefore, the inclusion of the state of knowledge variable was an attempt to incorporate the influence of the supply side of innovative activity.

The present empirical evidence, unfortunately, does not lend much support to the importance of the supply side of innovative activity. Interestingly, however, in the case of the machinery industry, we did observe a consistent negative sign about which something needs to be said. It is the same industry that was classified as a 'rudimentary' technology industry in the preceding section. A negative supply side effect seems to indicate certain constraints on the supply side which perhaps prevent any new breakthrough in that industry. This may be responsible for it being a 'rudimentary' technology industry.

5.3. Grouping of the Industries

A first look at the results did not seem to reveal any common characteristics across industries which could form the basis for grouping certain industries together. Such groupings would considerably facilitate the discussion of results. A more careful study of the results in conjunction with the ratio of R&D expenditure to net sales[1] disclosed the presence of some similarities in the results. Tables 5.6 and 5.7 present these ratios for private and total R&D expenditures, respectively, for the years 1957 and 1963-75. Total R&D expenditures to net sales ratio information is provided to give an impression of the extent of public expenditures on R&D over time and across different industries.

It was observed that the overall results are relatively better for high R&D-net sales ratio industries, particularly so when R&D price index Two is used. Though there is not much difference in results with regard to the R^2 statistic for the two price index specifications, the results are better as far as the significance of different coefficients is concerned. The latter observation also carries over to the comparison between high and low R&D-net sales ratio industries (see Tables 5.2-5.5).

There exists a considerable variation in the R&D-net sales ratio between different industries. The range being 0.004 (in the food and kindred products industry) to 0.035 (in the electrical and electronic equipment industry) as is shown in Table 5.6. The industries are divided into two groups; one with high and the other with low R&D-net sales ratios. The dividing line is the average R&D-net sales ratio for the entire manufacturing sector. This ratio is 0.019 and has remained relatively constant over

Table 5.6

Company R&D Funds as Percent of Net Sales in R&D Performing Manufacturing Companies, by Industry; 1957 and 1963 - 1975

Industry	SIC code	1957	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	Average
Food & kindred products	20	(1)	(1)	(1)	0.4	0.4	0.5	0.5	0.4	0.5	0.5	0.4	0.4	0.4	0.4	0.4364
Paper & allied products	26	0.6	0.8	0.8	0.8	(1)	(1)	(1)	(1)	(1)	(1)	0.8	(1)	(1)	(1)	0.7600
Chemicals & allied products	28	3.1	3.6	3.8	3.7	3.8	4.0	3.7	3.8	3.5	3.4	3.3	3.1	3.0	3.3	3.5071
Petroleum refining & extraction	29, 13	0.7	1.2	1.0	0.9	0.9	0.8	0.8	0.9	0.9	0.8	0.7	0.7	0.5	0.6	0.8143
Rubber products	30	1.1	1.6	1.6	1.7	1.7	1.7	1.8	1.7	1.7	1.7	1.7	1.6	(1)	(1)	1.6333
Stone, clay & glass products	32	(2)	1.6	1.5	1.5	1.5	1.7	1.6	1.7	1.7	1.6	1.5	1.5	1.5	1.5	1.4534
Primary metals	33	0.5	0.7	0.7	0.7	0.7	0.8	0.8	0.8	0.8	0.8	0.7	0.6	0.5	0.7	0.7000
Fabricated metal products	34	1.1	1.4	1.3	1.2	1.1	1.2	1.2	1.2	1.1	1.1	1.1	1.1	1.1	1.2	1.1714
Machinery	35	2.0	3.1	3.2	3.1	3.0	3.2	3.1	3.3	3.3	3.2	3.2	3.4	3.3	3.5	3.1357
Electrical equipment & communication	36, 48	2.6	3.6	3.6	3.6	3.4	3.5	3.7	3.6	3.5	3.6	3.6	3.6	3.7	3.9	3.5357
Motor vehicles & transportation equipment	371, 373-75, 79	2.1	2.5	2.6	2.3	2.4	2.5	2.3	2.5	2.8	2.6	{2.8 0.5	{2.9 0.4	{3.2 (1)	{3.0 (1)	2.6714
Total		1.5	1.9	2.0	2.0	2.0	2.1	2.1	2.2	2.2	2.1	2.0	2.0	1.9	1.9	1.9990

(1) Not separately available, but included in total.
(2) Data included in the other manufacturing industries group.

Source: Research and Development in Industry, 1975, National Science Foundation, Washington, D.C., Jan., 1977, Table B-37.

Table 5.7

Total R&D Funds as Percent of Net Sales in R&D Performing Manufacturing Companies, by Industry; 1957 and 1963 - 1975

Industry	SIC code	1957	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	Average
Food & kindred products	20	0.3	0.4	0.4	0.4	0.4	0.5	0.5	0.4	0.5	0.5	0.4	0.4	0.4	0.4	0.4214
Paper & allied products	26	0.6	0.8	0.8	0.8	0.9	0.9	0.9	1.0	0.9	0.9	0.8	0.7	0.8	0.9	0.8357
Chemicals & allied products	28	3.5	4.3	4.5	4.3	4.4	4.6	4.2	4.2	3.9	3.8	3.6	3.5	3.4	3.6	3.9857
Petroleum refining & extraction	29,13	0.7	1.0	1.1	1.0	0.9	0.8	0.8	0.9	1.0	0.9	0.8	0.7	0.6	0.6	0.8428
Rubber products	30	1.7	2.3	2.0	1.9	1.9	1.9	2.0	1.9	1.9	1.8	1.9	1.8	1.7	1.7	1.8857
Stone, clay & glass products	32	-	1.6	1.6	1.6	1.5	1.8	1.6	1.7	1.7	1.7	1.6	1.5	1.5	1.5	1.4693
Primary metals	33	0.5	0.8	0.8	0.8	0.7	0.8	0.8	0.8	0.8	0.8	0.7	0.6	0.5	0.7	0.7714
Fabricated metal products	34	1.6	1.6	1.5	1.3	1.3	1.3	1.3	1.2	1.2	1.1	1.1	1.2	1.2	1.2	1.15
Machinery	35	3.4	4.2	4.2	4.0	3.9	4.2	4.1	3.9	3.8	3.9	3.9	4.0	3.9	4.1	3.9642
Electrical equipment & communication	36,48	7.6	10.1	9.9	9.1	8.5	8.6	8.5	7.9	7.4	7.3	7.3	7.2	6.9	7.1	8.1
Motor vehicles & transportation equipment	371, 373-75, 79	2.9	3.4	3.6	3.1	3.2	3.4	3.1	3.1	3.5	3.1	{3.3 {0.6	{3.5 {0.5	{3.7 {0.6	{3.5 {0.5	3.4714
Total		3.4	4.5	4.6	4.3	4.2	4.2	4.0	4.0	3.7	3.5	3.4	3.3	3.0	3.1	3.8

Source: Research and Development in Industry, 1975, National Science Foundation, Washington, D.C., Table B-36, 1977.

time.[2] Therefore, the industries with average or higher than average R&D-net sales ratios are grouped together to constitute what shall henceforth be called the High R&D industries. The following industries are included in this group:

(i) Transportation equipment
(ii) Electrical and electronic equipment
(iii) Machinery
(iv) Chemicals and allied products.

The remaining industries which have lower than the average R&D-net sales ratio form the second group, and shall henceforth be called the Low R&D industries. These industries are;

(i) Food and kindred products
(ii) Paper and allied products
(iii) Petroleum and coal products
(iv) Rubber and plastic products
(v) Stone, clay and glass products
(vi) Primary metals
(vii) Fabricated metal products.

5.4. Absolute Value of the Coefficients

The results of the estimation are reported in Tables 5.8-5.20 of which Tables 5.8-5.11 contain the results for the High R&D, and the rest for the Low R&D industries.

Table 5.8

Determinants of Private R&D Expenditures: Ordinary Least Squares and Cochrane-Orcutt Iterative Technique Estimates for the Transportation Equipment Industry. Estimation Period: 1957-1976

Procedure	Dependent variable	Constant	Independent variables							R^2	D-W statistic
			Y	w/PRD	q/PRD	$(K/Y)_{-1}$	$(L/Y)_{-1}$	C_{-1}	t		
OLS	RD_1 *	0.7735 (0.2793)	0.3279 (2.7748)	0.4707 (1.5200)	-5.4057 (1.2986)	0.6364 (3.0946)	-0.3514 (3.3946)	-	0.0027 (1.2662)	0.9935	1.9525
OLS	RD_1	-2.3627 (0.6488)	0.6154 (4.9207)	0.4442 (1.0461)	-8.9029 (1.5782)	-	-	0.0734 (1.0621)	0.0030 (0.9223)	0.9868	1.6506
CORC	RD_1 *	2.8467 (0.7974)	0.4630 (3.7915)	1.0174 (2.4808)	-1.3294 (0.2474)	-	-	0.0808 (1.5257)	0.0017 (0.7152)	0.9911	1.7481
OLS	RD_2 *	9.3525 (4.0316)	0.1341 (1.3169)	1.0903 (8.1779)	0.1801 (2.0768)	0.7737 (4.1260)	-0.4239 (4.4758)	-	0.0015 (0.8025)	0.9867	1.9488
OLS	RD_2	6.7474 (1.7716)	0.4442 (3.2587)	1.2866 (5.9327)	-0.0964 (1.1950)	-	-	0.0854 (1.1205)	0.0019 (0.5745)	0.9637	1.4667
CORC	RD_2 *	-1.4718 (0.3861)	0.4780 (4.8291)	0.8048 (3.9283)	-0.1039 (1.5869)	-	-	0.0544 (1.1419)	0.0011 (0.5370)	0.9756	1.8199

The numbers in the parentheses are the t- statistics for the respective coefficients.

Table 5.9

Determinants of Private R&D Expenditures: Ordinary Least Squares and Cochrane-Orcutt Iterative Technique Estimates for the Electrical and Electronic Equipment Industry. Estimation Period: 1957-1976

Procedure	Dependent variable	Constant	Independent variables								D-W statistic
			Y	w/PRD	q/PRD	$(K/Y)_{-1}$	$(L/Y)_{-1}$	C_{-1}	t	R^2	
OLS	RD_1 *	3.8164 (4.4136)	0.3578 (4.9594)	1.0481 (3.8136)	1.0774 (0.6606)	0.6023 (5.8201)	-0.2721 (5.9541)	-	0.0012 (1.3017)	0.9975	2.1539
OLS	RD_1 *	3.0520 (1.9640)	0.7029 (10.3870)	1.2236 (2.4981)	0.0115 (0.0039)	-	-	0.0506 (0.9949)	0.0030 (1.1606)	0.9914	1.7967
OLS	RD_2 *	6.3403 (4.6151)	0.2927 (3.5745)	0.9840 (11.3477)	0.1199 (1.9517)	0.6469 (6.3842)	-0.2951 (6.4960)	-	0.0031 (2.0917)	0.9972	2.0455
OLS	RD_2 *	3.0981 (1.2245)	0.7062 (7.7868)	1.1869 (7.0692)	-0.1899 (2.5003)	-	-	0.0505 (0.9207)	0.0030 (0.9870)	0.9887	1.7763

The numbers in the parentheses are the t-statistics for the respective coefficients.

Table 5.10

Determinants of Private R&D Expenditures: Ordinary Least Squares and Cochrane-Orcutt Iterative Technique Estimates for the Machinery Industry. Estimation Period: 1957-1976

Procedure	Dependent variable	Constant	Independent variables								D-W statistic
			Y	w/PRD	q/PRD	$(K/Y)_{-1}$	$(L/Y)_{-1}$	C_{-1}	t	R^2	
OLS	RD_1	-46.5585 (0.9148)	0.7657 (3.3961)	0.2553 (0.3418)	-29.8348 (0.9651)	0.5908 (1.6966)	-0.3211 (1.8854)	-	-0.0039 (0.7146)	0.9746	0.8175
CORC	RD_1 *	37.9463 (3.0210)	0.3112 (4.9975)	1.5232 (8.4050)	20.3779 (2.6827)	0.6287 (7.0328)	-0.3522 (7.7840)	-	-0.0061 (5.9243)	0.9989	2.0007
OLS	RD_1	-42.3766 (0.7735)	0.9598 (4.5176)	0.5192 (0.6764)	-27.0284 (0.8105)	-	-	-0.0817 (0.6085)	-0.0043 (0.6748)	0.9676	0.9992
CORC	RD_1 *	87.6690 (3.4027)	0.4537 (4.4945)	2.4747 (6.6703)	50.8784 (3.2628)	-	-	0.1690 (3.3248)	-0.0055 (2.3489)	0.9954	2.1471
OLS	RD_2	7.6700 (1.0103)	0.7738 (2.9877)	1.2895 (2.3426)	0.0554 (0.2580)	0.4514 (1.1786)	-0.2508 (1.3124)	-	-0.0079 (1.0450)	0.9078	0.9410
CORC	RD_2 *	3.8989 (2.4101)	0.2231 (3.7662)	0.9469 (8.1022)	-0.0202 (0.4947)	0.7031 (6.5675)	-0.3860 (7.0665)	-	-0.0055 (4.3843)	0.9958	2.1306
OLS	RD_2	11.3217 (1.5533)	1.0174 (4.8968)	1.6814 (3.6754)	-0.0421 (0.2300)	-	-	0.0432 (0.3255)	-0.0120 (1.5044)	0.8942	1.1966
CORC	RD_2 *	12.4075 (4.2005)	0.7964 (9.6038)	1.8288 (9.6912)	-0.2150 (2.9632)	-	-	0.1112 (2.2639)	-0.0111 (3.7754)	0.9821	1.8009

The numbers in the parentheses are the t- statistics for the respective coefficients.

Table 5.11

Determinants of Private R&D Expenditures: Ordinary Least Squares and Cochrane-Orcutt Iterative Technique Estimates for the Chemicals and Allied Products Industry. Estimation Period: 1957-1976

Procedure	Dependent variable	Constant	Independent variables							R^2	D-W statistic
			Y	w/PRD	q/PRD	$(K/Y)_{-1}$	$(L/Y)_{-1}$	C_{-1}	t		
OLS	RD_1	3.5985 (2.7682)	0.4750 (1.2196)	0.8215 (1.2341)	-0.8538 (0.1691)	0.0786 (0.1571)	-0.0436 (0.1243)	-	-0.0057 (1.1376)	0.9823	0.6529
CORC	RD_1 *	6.1774 (12.9286)	0.0282 (0.2288)	1.0564 (4.8637)	-0.2115 (0.1285)	0.1173 (0.7203)	-0.0951 (0.8366)	-	-0.0016 (1.0658)	0.9976	1.8843
OLS	RD_1	3.3471 (4.7877)	0.5268 (6.1460)	0.8341 (1.8017)	-0.9088 (0.3007)	-	-	-0.0398 (0.7541)	-0.0070 (2.2108)	0.9826	0.7593
CORC	RD_1 *	6.0801 (12.9631)	0.0829 (0.8330)	0.9192 (5.1419)	-1.1950 (0.9772)	-	-	-0.0280 (1.7254)	-0.0019 (1.6717)	0.9973	1.9464
OLS	RD_2 *	-6.9748 (3.2707)	0.2637 (2.0832)	0.2701 (1.8342)	0.0092 (0.1234)	0.2529 (1.4000)	-0.1838 (1.4549)	-	-0.0036 (1.6441)	0.9661	1.1905
CORC	RD_2	1.0398 (0.6662)	0.0805 (1.3615)	0.7857 (8.2652)	-0.0848 (2.6439)	0.1310 (1.5064)	-0.1069 (1.7662)	-	-0.0024 (2.9641)	0.9911	2.6232
OLS	RD_2 *	-7.3146 (3.2738)	0.4403 (8.6473)	0.3635 (2.6377)	-0.0509 (0.9579)	-	-	0.0087 (0.2576)	-0.0060 (3.1032)	0.9602	1.3114
CORC	RD_2	-1.6736 (0.9575)	0.2589 (5.9598)	0.7199 (6.6272)	-0.1302 (4.5885)	-	-	0.0422 (2.7548)	-0.0036 (3.9866)	0.9867	2.6402

The numbers in the parentheses are the t-statistics for the respective coefficients.

In all these Tables RD_1 and RD_2 are the R&D expenditures as the dependent variable when the R&D price index One and Two respectively, are used in the specification. The very first column in all the tables indicates the procedure (OLS or CORC) to which the results correspond in each row of the Tables.

The value of the output coefficient shows a marked pattern for the alternative state of technology specifications. Its absolute value is almost twice as large when the unit cost specification rather than the capital- and labour-output ratios specification of the state of technology is employed. It would be recalled from an earlier discussion in section 5.2.2. that a change in unit cost derives its importance from the volume of output on which it is applicable. When unit cost is employed as the state of technology specification, the output variable may capture some of the variation attributable to unit cost due to interaction between these variables. On the other hand, it is also possible that the capital- and labour-output ratios as the alternative state of technology variables are capturing some of the output effect since they are also interrelated. The analysis falls short of determining which of these explanations is correct.

The second important pattern emerges with respect to the absolute value of the coefficients of the capital-and labour-output ratios. With the exceptions of the rubber and plastic products industry (which also was an exception with regard to the pattern of the signs of these coefficients as noted earlier in section 5.2.4.) and the food and kindred products industry, the absolute value of the capital-output ratio coefficient is almost twice as large as that of the labour-output ratio. In the food and kindred products industry, the reverse is true, i.e., the absolute value of the coefficient of the labour-output ratio is twice as large as that of capital-output ratio. It should be recalled that the food and kindred products industry was also an exception but with regard to the coefficient of unit cost, it was the only industry which had a negative sign for the unit cost specification of the state of technology under both the R&D price indices. These observations are discussed further when the individual industry results are examined.

In the previous discussion (section 5.2.4.) not much could be said about classifying different industries as having 'mature' or 'rudimentary' technology. In the light of the present evidence, it seems, we could proceed somewhat further. Considering that the sign of the capital-output ratio coefficient is positive while that of the labour-output ratio is negative, and also considering that the absolute value of the capital-output ratio coefficient is almost twice as much as that of the labour-output ratio coefficient, most of the industries would seem close to having 'rudimentary' rather than 'mature' technology. The positive effect of capital-output ratio outweighs the negative effect of labour-output ratio (see Figure 3.II in Chapter Three).

Another observation with regard to the absolute value of the coefficients concerns the coefficient of the state of knowledge. Besides being significant in barely a handful of estimated equations, its absolute value is invariably very small, beginning at two places after the decimal in most of the cases. Therefore, the influence of the supply side of innovative activity is, according to the present evidence, extremely meagre.

5.5. High R&D Industries

We have already mentioned that the results, in general, are relatively better for the High R&D as compared to the Low R&D industries particularly with respect to R&D price index Two. It would seem that in the High R&D industries, decisions with regard to the level of R&D expenditure place more emphasis on the R&D personnel cost (recall that R&D price index Two was constructed by using the wage rates of R&D personnel). This could not be said for the Low R&D industries as the results are not relatively better for one of the two R&D price indices. For this reason more significance is accorded to the results with respect to the R&D price index Two in the following discussion of the High R&D industries.

Tables 5.8-5.11 report the results for the four industries belonging to this group. Output, relative factor prices, and capital- and labour-output ratios turn out to be the most significant variables in determining R&D expenditures. These variables have significant coefficients in almost all the industries in this group, although of the two relative factor price variables only the relative wage rate coefficient is significant in all cases. The relative user cost coefficient is significant in only a few equations though in the electrical and electronic equipment industry it is significant in both the cases when R&D price index Two is used.

The electrical and electronic equipment industry yields the best results of all the industries. This is not surprising given that it is the most research-intensive industry as shown by the ratio of R&D expenditures to net sales. This ratio is the highest for this industry of all the industries under study. All the coefficients, including that of 't', are significant when the capital- and labour-output ratio specification of the state of technology is used. But under the unit cost specification, the coefficients of both unit cost and 't' become insignificant.

The results are relatively poor for the chemicals and allied products industry as compared to the other industries in the High R&D group. In this industry only output and the relative wage rate are significant variables.

The case of the machinery industry (which was classified as a 'rudimentary' technology industry according to the sign of the coefficient with respect to the unit cost in section 5.2.4.) can now be considered in conjunction with the signs and the absolute value of the coefficients of capital- and labour-output ratio. Evidence with respect to this latter set of coefficients do not single out this industry as having 'rudimentary' technology. But also considering the consistent negative sign of the state of knowledge coefficient and the speculation about some supply side constraints in section 5.2.5 above, this industry would appear to be closer to 'rudimentary' technology as compared to the other industries in this group.

Another explanation for the negative sign of the state of knowledge coefficient in this industry would be to deny the presence of decreasing returns to innovative activity. That way the denominator on the right hand side of the equation

$$\frac{dRD}{dt} = - \frac{\partial^2 C/\partial RD \partial t}{\partial^2 C/\partial RD^2}$$

as presented in section 3.5 (Chapter Three) would be negative and thus dRD/dt < 0. This, however, would not be of great help. Since $\partial^2 C/\partial RD^2$ also appear in the denominators of the coefficients of other variables, we shall need to change the signs of other coefficients as well. The consistency with regard to the signs of all the other coefficients in most of the industries renders this choice unattractive.

All in all, the model does seem to explain R&D expenditure behaviour reasonably well in the High R&D industries.

5.6. Low R&D Industries

Whereas in the High R&D industries the results, as far as the number of significant coefficients were concerned, were relatively better for R&D price index Two, no similar pattern is observed in the Low R&D industries. Moreover, in the High R&D industries, the R^2 statistic showed an invariance with respect to the two R&D price indices. But in the Low R&D industries that is not true. There is a variability in some industries. For example, in three industries (primary metals, petroleum and coal products, and fabricated metal products) the R^2 statistic is lower for R&D price index Two. It is lowest for the primary metals industry (0.32 and 0.50) while in the remaining two industries it is in the range of 0.6 to 0.85.

For the stone, clay and glass products industry the aforementioned comparison could not be made because, as earlier mentioned, for this industry R&D price index Two could not be constructed. On the basis of the R^2 statistic, the results seem relatively strong for the R&D price index One in the Low R&D industries, unlike the High R&D industries.

There are altogether seven industries in the Low R&D industries group. It was natural to look for similarities of results in order to provide a common ground for discussion. It was found that in a subset of these industries certain variables show a consistent behaviour while in another subset a different variable does. In the following four industries, only the state of technology variables (capital- and labour-output ratios) show some consistency:

(i) Food and kindred products

(ii) Rubber and plastic products

(iii) Paper and allied products

(iv) Primary metals

and henceforth shall be referred to as the Low R&D set one industries. In the other three industries, whereas the state of technology variables do not show any consistency, the relative wage rate variable turns out to be remarkably consistent. This observation strengthened our belief that the remaining three industries should form the Low R&D set two industries which are;

(i) Petroleum and coal products

(ii) Fabricated metal products

(iii) Stone, clay and glass products.

5.6.1. Low R&D Industries Set One

Tables 5.12-5.15 contain the results pertaining to the Low R&D set one industries. An examination of Table 5.12 (also see Tables 5.2-5.5) shows that the results for the food and kindred products industry are relatively better than any other industry in the whole Low R&D group. Indeed they are very close to the results for the High R&D industries, particularly so with respect to the R&D price index Two. This seems particularly strange given that this industry has the lowest R&D expenditure-net sales ratio.

In the food and kindred products industry the coefficients of output, the relative wage rate, and the state of technology are generally significant. The output coefficient is significant in three of the four estimated equations as is the relative wage rate coefficient. The state of technology coefficients are also significant. These results would suggest that the food and kindred products industry should belong to the High R&D industries, but this is not the case.

Table 5.12

Determinants of Private R&D Expenditures: Ordinary Least Squares and Cochrane-Orcutt Iterative Technique Estimates for the Food and Kindred Products Industry. Estimation Period: 1957-1975

Procedure	Dependent variable	Independent variables: Constant	Y	w/PRD	q/PRD	$(K/Y)_{-1}$	$(L/Y)_{-1}$	C_{-1}	t	R^2	D-W statistic
OLS	RD_1	20.6670 (1.2040)	0.5987 (1.7769)	1.1748 (4.3536)	5.3441 (0.7405)	0.2926 (1.0150)	-2.3199 (2.0731)	-	0.0002 (0.0539)	0.9909	1.6121
CORC	RD_1 *	17.3266 (0.9393)	0.4797 (1.3894)	1.0632 (2.6310)	3.3689 (0.3611)	0.4787 (1.4748)	-2.2701 (1.8977)	-	0.0004 (0.1524)	0.9915	1.8331
OLS	RD_1 *	-5.5474 (0.6381)	1.3564 (9.0510)	0.9653 (4.7153)	-1.0011 (0.1754)	-	-	-0.5056 (2.0180)	-0.0052 (1.0684)	0.9899	1.7779
OLS	RD_2 *	-0.4239 (0.0614)	0.5480 (2.0018)	0.4518 (1.5157)	0.0593 (0.7937)	0.5199 (1.8072)	-1.4876 (2.0043)	-	-0.0011 (0.4002)	0.9315	1.4634
CORC	RD_2	-8.7277 (1.1163)	0.0397 (0.1635)	0.4748 (2.4788)	-0.00005 (0.00008)	0.4783 (1.3859)	0.5125 (0.4192)	-	-0.0013 (0.6702)	0.9330	2.8157
OLS	RD_2 *	-10.7991 (2.8644)	1.2594 (8.7727)	0.5545 (2.2514)	0.0017 (0.0368)	-	-	-0.5697 (2.7316)	-0.0077 (1.9823)	0.9253	1.9565

The numbers in the parentheses are the t- statistics for the respective coefficients.

Table 5.13

Determinants of Private R&D Expenditures: Ordinary Least Squares and Cochrane-Orcutt Iterative Technique Estimates for the Rubber and Plastic Products Industry. Estimation Period: 1957-1973

Procedure	Dependent variable	Constant	Independent variables							R^2	D-W statistic
			Y	w/PRD	q/PRD	$(K/Y)_{-1}$	$(L/Y)_{-1}$	C_{-1}	t		
OLS	RD_1	36.5129 (2.0115)	-0.8866 (1.5085)	4.3428 (2.3976)	98.2973 (1.9456)	0.3230 (0.5286)	0.8337 (0.8604)	-	0.0915 (1.4306)	0.9796	1.2900
CORC	RD_1 *	0.2812 (0.0451)	-0.4845 (2.7168)	0.9652 (1.5344)	-3.6773 (0.2115)	0.7522 (3.0277)	0.7331 (2.6299)	-	-0.0081 (0.3564)	0.9973	1.8349
OLS	RD_1 *	35.1901 (2.0980)	-0.4119 (0.9759)	4.0794 (2.5470)	83.2922 (1.8660)	-	-	0.6194 (1.7349)	0.0915 (2.3076)	0.9802	1.3467
CORC	RD_1	-3.4081 (0.3347)	-0.0956 (0.4049)	0.3916 (0.4019)	-21.0352 (0.7740)	-	-	0.1237 (0.4600)	0.0336 (1.072)	0.9915	1.6681
OLS	RD_2	0.7975 (0.1252)	-0.1496 (0.2859)	0.7636 (1.5368)	0.1617 (0.5750)	0.6248 (0.8992)	0.1792 (0.1667)	-	0.0153 (0.2605)	0.9018	0.3802
CORC	RD_2 *	0.7451 (0.4838)	-0.4455 (3.6901)	0.9429 (7.6504)	-0.0481 (0.6945)	0.5644 (2.3345)	0.6582 (2.8216)	-	-0.0169 (0.7305)	0.9894	2.2011
OLS	RD_2	1.8870 (0.3828)	0.0467 (0.1212)	0.9474 (2.2188)	-0.0768 (0.3780)	-	-	0.6725 (1.6481)	0.0477 (1.3335)	0.9100	0.5913
CORC	RD_2 *	0.6064 (0.2805)	0.2470 (1.4529)	0.8327 (4.3132)	-0.0753 (0.6839)	-	-	0.0301 (0.1242)	0.0375 (1.5091)	0.9702	1.7512

The numbers in the parentheses are the t- statistics for the respective coefficients.

Table 5.14

Determinants of Total R&D Expenditures: Ordinary Least Squares and Cochrane-Orcutt Iterative Technique Estimates for the Paper and Allied Products Industry. Estimation Period: For RD_1: 1953-1976; For RD_2: 1957-1976

Procedure	Dependent variable	Constant	Y	w/PRD	q/PRD	$(K/Y)_{-1}$	$(L/Y)_{-1}$	C_{-1}	t	R^2	D-W statistic
			Independent variables								
OLS	RD_1	15.9638 (0.4740)	1.6428 (4.1223)	1.0888 (2.3786)	13.0103 (0.6018)	0.2056 (0.4289)	-0.0512 (0.1816)	-	-0.0111 (1.8593)	0.9839	1.5640
CORC	RD_1 *	-62.3234 (1.6712)	1.1726 (2.4301)	0.0988 (0.1829)	-39.6518 (1.6797)	-0.0095 (0.0151)	-0.0112 (0.0303)	-	-0.0031 (0.7556)	0.9874	1.7832
OLS	RD_1	-19.4312 (0.6626)	1.5591 (9.5978)	0.6789 (1.5777)	-10.5315 (0.5478)	-	-	0.0154 (0.1191)	-0.0018 (0.2945)	0.9806	1.2042
CORC	RD_1 *	-74.0055 (2.2130)	1.2239 (3.3929)	-0.0717 (0.1387)	-47.0918 (2.2172)	-	-	0.0985 (1.1765)	-0.0017 (0.4404)	0.9881	1.8080
OLS	RD_2	-8.2657 (1.5713)	1.4336 (2.6563)	0.1796 (0.5333)	0.5208 (2.3016)	0.9226 (1.1668)	-0.4542 (0.9746)	-	-0.0105 (1.7584)	0.9677	1.5268
CORC	RD_2 *	-2.5260 (0.8715)	0.2542 (0.6375)	0.5744 (2.7670)	0.1051 (0.7431)	0.9175 (1.8309)	-0.5389 (1.8238)	-	-0.0005 (0.1418)	0.9802	1.9424
OLS	RD_2	-7.5717 (1.4065)	1.6863 (7.2279)	0.6136 (1.5850)	0.1524 (0.9202)	-	-	-0.0677 (0.1529)	-0.0056 (0.8040)	0.9504	1.2409
CORC	RD_2 *	-3.1652 (1.1393)	0.4485 (1.3332)	0.7703 (4.1474)	-0.0992 (1.0944)	-	-	0.0370 (0.4916)	-0.0009 (0.2412)	0.9756	1.8756

The numbers in the parentheses are the t- statistics for the respective coefficients.

Table 5.15

Determinants of Private R&D Expenditures: Ordinary Least Squares and Cochrane-Orcutt Iterative Technique Estimates for the Primary Metals Industry. Estimation Period: 1957-1976

Procedure	Dependent variable	Independent variables: Constant	Y	w/PRD	q/PRD	$(K/Y)_{-1}$	$(L/Y)_{-1}$	C_{-1}	t	R^2	D-W statistic
OLS	RD_1 *	-35.6153 (2.1625)	0.8247 (4.2332)	-0.0737 (0.2227)	-20.9175 (2.1227)	1.1026 (3.9767)	-0.6781 (3.9576)	-	-0.0168 (3.5055)	0.9752	1.7973
CORC	RD_1	9.7776 (0.5090)	0.0724 (0.2639)	1.0448 (2.6871)	3.6100 (0.3279)	0.4774 (1.2900)	-0.3080 (1.2997)	-	-0.0089 (2.5089)	0.9858	1.2068
OLS	RD_1 *	-36.6144 (1.5789)	0.9736 (4.2129)	0.2573 (0.6071)	-21.7983 (1.5735)	-	-	0.1983 (1.3791)	-0.0044 (0.6554)	0.9517	1.4760
CORC	RD_1	12.8922 (0.6677)	0.0028 (0.0105)	1.2025 (3.2925)	5.0821 (0.4572)	-	-	0.0490 (0.6960)	-0.0072 (1.9980)	0.9844	1.2872
OLS	RD_2 *	-8.1160 (2.8223)	0.0121 (0.0377)	0.0280 (0.1289)	0.2293 (2.2495)	0.7645 (2.9797)	-0.4810 (3.1104)	-	-0.0027 (0.3824)	0.5041	1.4679
CORC	RD_2	-1.5980 (0.4555)	0.0048 (0.0221)	0.5882 (2.5090)	0.0511 (0.5853)	0.4585 (1.4074)	-0.3034 (1.4624)	-	-0.0042 (0.9287)	0.6733	1.2582
OLS	RD_2 *	-11.4087 (3.7210)	-0.1438 (0.4483)	0.0278 (0.1172)	-0.0473 (0.7148)	-	-	0.2107 (2.0870)	0.0112 (1.6196)	0.3245	1.1409
CORC	RD_2	-2.7452 (0.7935)	-0.0583 (0.2974)	0.5951 (2.6251)	-0.0551 (1.1489)	-	-	0.0987 (1.5736)	-0.0008 (0.1764)	0.6667	1.3429

The numbers in the parentheses are the t- stastistics for the respective coefficients.

This apparent inconsistency, however, is explained when we look at the unit cost coefficient. In both the cases the coefficient is significant. What makes it unique is the fact that, unlike any other industry, the sign of this coefficient is negative. This was discussed earlier in section 5.2.4. There, on the basis of the present evidence,the food and kindred products industry was assumed to be a 'mature' technology industry. Nevertheless it was also proposed that any subsequent inference with regard to the state of technology would be based on a simultaneous consideration of both the state of technology variables, ie., capital- and labour-output ratios and unit cost. It would not be without interest to note that the absolute value of the unit cost coefficients in the present industry is more than two and a half times as large as the next largest coefficient for other industries (see for example, Table 5.15 which presents the next largest coefficient).

Evidence with respect to the capital- and labour-output ratio coefficients also suggests that this industry has a 'mature' technology. The coefficient of the capital-output ratio is positive while the coefficient of the labour-output ratio is negative as in all the other industries with the exception of the rubber and plastic products industry (see section 5.2.4.). Yet, there is something unique about those coefficients in the present case. It pertains to the absolute value of those coefficients. Earlier in section 5.4., it was pointed out that the absolute value of the capital-output ratio coefficient was almost twice the absolute value of the labour-output ratio coefficient whenever they had opposite signs with the exception of the present industry. On that basis, it was then proposed that except for the exceptional case of the food and kindred products industry all the industries seem to have close to a 'rudimentary' technology. The reverse is true for the food and kindred products industry. In this industry the absolute value of the negative labour-output ratio coefficient is almost three times the absolute value of the positive capital-output ratio coefficient. Therefore, the positive effect of a change in the capital-output ratio would be more than offset by a similar change in the labour-output ratio (see Chapter Three, Figure 3.II). This industry then presents a case of a 'mature' technology in the sense that there is not much room for improvement in its technology. There may exist some ridigities in the technological options that makes it so.

To clarify this point, consider the following example: In Figure 3.V (Chapter Three) the firm is presently producing at point 'A' on IPC_0 and I_{01}. The IPC_1 represents the innovation possibilities open to the firm for the next period. With everything else unchanged the firm would move to technique I_{11}, moving its production point to B which entails a unit cost saving of GH. Suppose for the given output, the total cost saving justifies the move to B, in the sense that the total cost saving was higher than the innovating cost, 'T'. The firm would undertake the required R&D expenditure. But now relax the assumption that everything else remains unchanged. Allow for the unit cost of output to increase, let us say, due to an increase in the wage rate. Now the optimal point on the IPC_1 is given by 'D' which implies a unit cost reduction of 'XZ'. For the same level of output, the total cost reduction now may not be sufficient to cover the innovating cost, 'T'. Therefore, the firm may not undertake the required expenditures and instead may stay at point 'E' on the old IPC. If the shape of IPC_1 were different, let us say it were bent towards the labour axis, it might have resulted in the firm undertaking the R&D expenditure since the unit cost saving 'XZ' would be larger. This then may be the kind of rigidity in the technological options underlying the conclusion that the food and kindred products industry has a 'mature' technology.

Opposite to the 'mature' technology of the food and kindred products industry is the case of the rubber and plastic products industry. This industry was classified as having 'rudimentary' technology on the evidence of the coefficients of capital- and labour-output ratio (see section 5.2.4.). The results for this industry are reported in

Table 5.13. Unlike any other industry, this industry has both the capital- and labour-output ratio coefficients with positive signs which according to the discussion in Chapter Three makes it a 'rudimentary' technology industry. The evidence with regard to the unit cost coefficient does not provide much help, since in both the cases when the unit cost specification is employed, its coefficient is insignificant. Even then it is interesting to note that in both the cases it is very close to being significant. The t-statistic being 1.74 and 1.65 against 1.79 needed to be significant. Furthermore, their absolute value is even larger than the absolute value in the food and kindred products industry as discussed previously, and their sign is positive. This evidence, though not conclusive by itself, supports the proposition that the rubber and plastic products industry could be characterized as a 'rudimentary' technology industry.

Relative factor price variables turn out to be significant in a few estimated equations. For example, the relative wage rate coefficient is significant in three out of four equations while the relative user cost is significant in only one equation for this industry. More than anything else it is hard to explain the negative output coefficients in this industry, particularly in view of the state of technology discussion above.

Before discussing the results for the remaining two industries in the Low R&D set one, we digress to present some results for total R&D expenditures especially because they pertain to the two industries discussed just above. The rubber and plastic products industry had only 17 observations, while the food and kindred products industry had 19 observations. When the analysis is carried out for total R&D expenditures the number of observations increases by three for the former and by four for the latter industry. For the former it adds years 1974-1976 while for the latter it adds years 1953-1956. The results for both of these industries are presented in Table 5.16 and 5.17.

As far as the variables other than the ones pertaining to the state of technology are concerned, there is no noticeable difference between these results and those for private R&D expenditures reported in Tables 5.12 and 5.13, although something could be said about the coefficient of output in the rubber and plastic products industry. However, as far as the state of technology variables are concerned, there are striking differences. They are different to the extent that the conclusions of the analysis carried out in the preceding pages are reversed. Note the following points:

(a) In the food and kindred products industry the strikingly negative unit cost coefficients are rendered insignificant now;

(b) Besides that the coefficient of the labour-output ratio now becomes almost one-half the coefficient

Table 5.16

Determinants of Total R&D Expenditures: Ordinary Least Squares and Cochrane-Orcutt Iterative Technique Estimates for the Food and Kindred Products Industry. Estimation Period: for RD_1: 1953-1976 for RD_2: 1957-1976

Procedure	Dependent variable	Constant	Independent variables							R^2	D-W statistic
			Y	w/PRD	q/PRD	$(K/Y)_{-1}$	$(L/Y)_{-1}$	C_{-1}	t		
OLS	RD_1	-2.0549 (0.2965)	0.5115 (3.2820)	0.7921 (4.7930)	-1.9466 (0.4287)	0.7697 (4.3283)	-0.4248 (4.3293)	-	0.0016 (0.5402)	0.9894	1.0117
CORC	RD_1 *	-5.5817 (0.7619)	0.5293 (2.5820)	0.7224 (4.0599)	-4.2018 (0.9091)	0.7836 (4.2651)	-0.4361 (4.1075)	-	0.0020 (1.0880)	0.9925	1.8332
OLS	RD_1	-7.4824 (0.7668)	1.0853 (7.8460)	0.8776 (3.7389)	-3.6916 (0.5649)	-	-	-0.0172 (0.1984)	0.0031 (0.6349)	0.9777	1.1702
CORC	RD_1 *	-11.0442 (1.2189)	1.2784 (8.7284)	0.7802 (3.5066)	-5.2075 (0.8821)	-	-	-0.0709 (1.1469)	0.0009 (0.2589)	0.9855	2.0258
OLS	RD_2	-7.0057 (2.0377)	0.6016 (2.4610)	0.4207 (1.5658)	0.1044 (1.5064)	0.6639 (2.6195)	-0.3660 (2.5779)	-	-0.0010 (0.3917)	0.9281	1.2420
CORC	RD_2 *	-3.7200 (1.6766)	0.1067 (0.5715)	0.5051 (3.3014)	0.0457 (1.0171)	0.5827 (2.8300)	-0.3380 (2.8957)	-	0.0003 (0.1855)	0.9463	2.2020
OLS	RD_2	-5.8353 (1.4724)	1.1974 (7.6749)	0.8275 (3.2182)	-0.0398 (0.9394)	-	-	-0.0528 (0.8243)	-0.0003 (0.0918)	0.8950	1.7333
CORC	RD_2 *	-8.6068 (2.4460)	0.8234 (4.2593)	0.5785 (2.4401)	-0.0969 (2.2037)	-	-	0.0186 (0.3236)	0.0011 (0.3875	0.8881	2.0473

The numbers in the paretheses are the t- statistics for the respective coefficients.

Table 5.17

Determinants of Total R&D Expenditures: Ordinary Least Squares and Cochrane-Orcutt Iterative Technique Estimates for the Rubber and Plastic Products Industry. Estimation Period: 1957-1976

Procedure	Dependent variable	Constant	Independent variables								D-W statistic
			Y	w/PRD	q/PRD	$(K/Y)_{-1}$	$(L/Y)_{-1}$	C_{-1}	t	R^2	
OLS	RD_1 *	8.0799 (1.8074)	-0.0558 (0.2126)	1.1952 (2.1199)	9.5944 (0.8322)	0.5635 (1.3801)	-0.3413 (1.9120)	-	0.0032 (0.6448)	0.9725	1.7381
OLS	RD_1 *	4.5270 (0.9973)	0.2528 (3.4838)	1.1505 (2.0921)	2.0536 (0.1702)	-	-	0.3859 (3.4866)	0.0075 (1.3502)	0.9725	1.8147
OLS	RD_2 *	-6.5719 (1.7159)	-0.2314 (1.0776)	-0.0631 (0.1969)	0.3673 (2.2914)	0.7338 (2.2284)	-0.3298 (2.3358)	-	0.0003 (0.0857)	0.7383	0.9613
CORC	RD_2	-7.7714 (4.0681)	-0.4103 (2.8399)	-0.0222 (0.1478)	0.1845 (2.0238)	0.5454 (2.5806)	-0.2487 (2.5974)	-	0.0004 (0.2413)	0.8656	2.3775
OLS	RD_2 *	-3.9377 (1.0395)	0.2176 (3.6297)	0.5292 (1.9364)	0.0061 (0.0650)	-	-	0.1871 (1.4788)	0.0039 (1.0096)	0.6786	1.2754
CORC	RD_2	-8.1119 (4.0597)	-0.3710 (2.4852)	0.0518 (0.3264)	0.0830 (1.2423)	-	-	-0.0074 (0.1045)	0.0010 (0.4912)	0.8367	2.2891

The numbers in the parentheses are the t- statistics for the respective coefficients.

of the capital-output ratio in absolute value (as in all the other industries) whereas formerly it was almost three times as large as the capital-output ratio coefficient. Therefore, the evidence with respect to the capital- and labour-output ratio variables is reversed while with respect to unit cost variable, 't', it is rendered inconclusive.

(c) In the rubber and plastic products industry, the coefficient of unit cost now becomes significant but the labour-output ratio coefficient assumes a negative sign and is one half the value of the capital-output ratio coefficient in absolute terms (as in all the other industries). This result would cast some doubt on the earlier conclusion that this industry has a 'rudimentary' technology. Nonetheless the present results still suggest a close to 'rudimentary' technology for this industry.

One encouraging observation is that the output coefficients are now positive. These differences in the results for private and total R&D expenditures suggested yet another experiment, this time excluding the additional observations. It was hoped that this experiment would determine whether the above changes were a result of a different data period or the change in the dependent variable. The estimation for the rubber and plastic products industry for total R&D expenditures was restricted to the same time period as the original estimation for private R&D expenditures (1957-73). The results, not reported here, caused another surprise. Only the output and state of knowledge coefficients were each significant once in two separate estimated equations. All the other coefficients were insignificant. It must also be pointed out that in other experiments with total R&D expenditures for which the results are not reported, the results were generally weaker than those for private R&D expenditures.

Tables 5.14 and 5.15 contain the results for the paper and allied products and the primary metals industries. In both of these industries the state of technology variables show a pattern more or less consistent with the behaviour in all the industries in this group. The output coefficient is significant only in the two equations using R&D price index One. In the paper and allied products industry the relative wage rate coefficient is only significant in the two equations using R&D price index Two. The relative user cost coefficient is significant in only one of the four equations for the paper and allied products industry, and in two out of four equations in the primary metals industry. The unit cost and the state of knowledge coefficients are both significant in only one single case.

This evidence suggests that in this set of Low R&D industries no generalizations can be made as to the influence of these variables. These variables do seem to affect R&D expenditures but we are unable to discern a consistent behaviour especially in the cases of the paper and allied products and the primary metals industries. In the food and kindred products and the rubber and plastic products industries this evidence, though not entirely conclusive, suggests that output and the relative wage rate have some influence in the determination of R&D expenditures.

5.6.2. Low R&D Industries Set Two

The results for the Low R&D set two industries are reported in Tables 5.18-5.20. The most striking observation about these results is the remarkable consistency with respect to the relative wage rate coefficient. The relative wage rate coefficient is significant in all the estimated equations. In the petroleum and coal products industry, besides the relative wage rate coefficient, the output coefficient is significant in the two estimated equations pertaining to unit cost specification of the state of technology. In one of these equations, the unit cost coefficient is also significant with a positive sign. This latter piece of evidence would indicate that the technology of the industry is 'rudimentary', i.e., that if the unit cost were higher, it would induce more R&D expenditures as argued in Chapter Three.

Table 5.18

Determinants of Private R&D Expenditures: Ordinary Least Squares and Cochrane-Orcutt Iterative Technique Estimates for the Petroleum and Coal Products Industry. Estimation Period: 1957-1975

Procedure	Dependent variable	Constant	Independent variables							R^2	D-W statistic
			Y	w/PRD	q/PRD	$(K/Y)_{-1}$	$(L/Y)_{-1}$	C_{-1}	t		
OLS	RD_1 *	5.5333 (2.9441)	0.0181 (0.0813)	0.9024 (7.8631)	-0.2812 (1.0261)	0.8425 (1.3489)	-1.2454 (2.5299)	-	-0.0052 (0.9528)	0.9970	1.4695
CORC	RD_1	4.9912 (2.4254)	0.0306 (0.1329)	0.9822 (8.5050)	-0.1016 (0.3573)	0.4988 (0.7891)	-0.6514 (1.1507)	-	-0.0025 (0.4187)	0.9975	1.4766
OLS	RD_1 *	2.3545 (1.5489)	0.5085 (1.9754)	0.9446 (8.7916)	-0.2125 (0.7142)	-	-	0.0277 (0.3781)	-0.0054 (0.7733)	0.9942	1.2676
CORC	RD_1	3.7131 (3.3273)	0.3203 (1.6660)	1.0427 (12.7901)	0.0218 (0.0983)	-	-	0.0950 (1.7627)	-0.0004 (0.0837)	0.9976	1.6551
OLS	RD_2 *	4.0687 (1.0107)	-0.0745 (0.3864)	0.8437 (3.7779)	-0.0078 (0.3807)	0.4710 (0.9384)	-0.9448 (2.1261)	-	-0.0006 (0.1757)	0.7480	1.2611
CORC	RD_2	0.9551 (0.2632)	0.0208 (0.1226)	0.7695 (4.0441)	-0.0101 (0.5610)	0.3927 (0.7433)	-0.4257 (0.8629)	-	-0.0006 (0.1839)	0.7730	1.4429
OLS	RD_2	-3.3160 (0.8478)	0.3746 (2.7258)	0.5904 (2.3676)	-0.0065 (0.3611)	-	-	0.0447 (0.6558)	-0.0005 (0.1231)	0.5970	1.1931
CORC	RD_2 *	-1.6670 (0.6488)	0.3723 (3.9835)	0.6984 (4.2710)	-0.0179 (1.5410)	-	-	0.1078 (2.2976)	-0.0006 (0.2252)	0.8095	1.8191

The numbers in the parentheses are the t- statistics for the respective coefficients.

Table 5.19

Determinants of Private R&D Expenditures: Ordinary Least Squares Estimates for the Fabricated Metal Products Industry.

Estimation Period: 1957-1976

Procedure	Dependent variable	Constant	Independent variables							R^2	D-W statistic
			Y	w/PRD	q/PRD	$(K/Y)_{-1}$	$(L/Y)_{-1}$	C_{-1}	t		
OLS	RD_1 *	9.4901 (0.6559)	-0.0427 (0.1864)	1.1013 (2.8790)	4.4452 (0.3838)	0.6297 (1.6910)	-0.2993 (1.8183)	-	0.0017 (0.5273)	0.9847	2.2401
OLS	RD_1 *	-2.8921 (0.2057)	0.3314 (2.9211)	0.9934 (2.3996)	-4.8209 (0.4202)	-	-	0.0601 (0.7602)	0.0012 (0.3229)	0.9805	2.2445
OLS	RD_2 *	-2.8497 (1.5098)	-0.0696 (0.5150)	0.5967 (4.3780)	-0.0562 (0.5686)	0.3445 (1.4491)	-0.1766 (1.6672)	-	0.0023 (1.0872)	0.7580	1.9539
OLS	RD_2 *	-4.2707 (2.3403)	0.1087 (1.2043)	0.6731 (4.9549)	-0.1813 (2.9064)	-	-	0.0716 (1.3546)	0.0017 (0.6756)	0.6956	1.7524

The numbers in the parentheses are the t- statistics for the respective coefficients.

Table 5.20

Determinants of Total R&D Expenditures: Ordinary Least Squares and Cochrane-Orcutt Iterative Technique Estimates for the Stone, Clay, and Glass Products Industry. Estimation Period: 1953-1976

Procedure	Dependent variable	Constant	Independent variables: Y	w/PRD	q/PRD	$(K/Y)_{-1}$	$(L/Y)_{-1}$	C_{-1}	t	R^2	D-W statistic
OLS	RD_1	7.4363 (0.2738)	0.0041 (0.0127)	0.7962 (1.7678)	2.8237 (0.1639)	1.1262 (2.9873)	-0.5820 (3.0418)	-	-0.0057 (0.9550)	0.9633	1.2069
CORC	RD_1 *	2.1416 (0.1237)	-0.0574 (0.2727)	1.0192 (3.0580)	-1.4472 (0.1320)	-0.1711 (0.3650)	0.0714 (0.2819)	-	-0.0039 (1.4162)	0.9833	1.9790
OLS	RD_1	-51.7967 (1.8747)	0.6974 (3.6400)	0.0011 (0.0022)	-33.6019 (1.8677)	-	-	0.2133 (1.3713)	0.0051 (0.6406)	0.9487	0.9338
CORC	RD_1 *	-6.3049 (0.3782)	-0.0817 (0.4282)	0.8502 (2.7409)	-6.8738 (0.6499)	-	-	0.1164 (1.7769)	-0.0018 (0.6003)	0.9848	1.9217

The numbers in the parentheses are the t- statistics for the respective coefficients.

Supportive evidence from the capital- and labour-output ratio specification of the state of technology is not very helpful in settling this issue. In both the cases when the capital- and labour-output ratio specification is used, only the labour-output ratio coefficient is significant and is negative in sign. Considered in isolation from the capital-output ratio variable, this indicates a 'mature' technology industry, in the sense that at least the technological change is not consonant with a higher labour-output ratio. But it is not very fruitful to consider the labour-output ratio in isolation from the capital-output ratio variable. Therefore, it would be more appropriate to reserve any judgement about the state of technology in this industry.

A brief look at Table 5.19 indicates that in the fabricated metal products industry, the results are even weaker than in the petroleum and coal products industry. Other than the relative wage rate, the coefficient of output, relative user cost, and the labour-output ratio are each significant in a different equation. The effect of any variable other than the relative wage rate on R&D expenditure in this industry has to be taken with considerable caution.

The results for the stone, clay and glass products industry could only be estimated for R&D price index One and are reported in Table 5.20. There are only two estimated equations, one each for each specification of the state of technology. With the capital- and labour-output ratio specification only the relative wage rate coefficient is significant. However, with the unit cost specification, the unit cost coefficient also is significant. In the absence of any supporting evidence from the capital- and labour-output ratio coefficients and the absence of results for the R&D price index Two no concrete description of the state of technology in this industry can be made.

Nevertheless, for the Low R&D set two industries, the Hicksian hypothesis that a change in relative factor prices is a spur to innovative activity is strongly supported.

5.7. Summary of the Results

When all the industries are considered together, the relative wage rate emerges as the most consistently important variable. It is significant in 33 estimated equations while output is significant in only 25. This point is even more strongly supported by the fact that of the nine equations where the relative wage rate coefficient was insignificant, four belonged to just one industry, namely the primary metals industry. In this way the Hicksian proposition that relative factor price changes are a spur to innovative activity, though entirely neglected in the literature, is strongly validated by the empirical analysis. Except in the primary metals industry where, on the basis of present evidence, it is not possible to discern its importance, the Hicksian induced innovation hypothesis is supported by the empirical evidence.

The state of technology also seems to exert a considerable influence on the determination of innovative activity particularly in the High R&D and the Low R&D set one industries. Moreover it seems that the capital- and labour-output ratios fare better than unit cost as the state of technology specification.

The state of knowledge as a surrogate for the supply side influence on innovative activity performed rather poorly as it was significant in only eight of the 42 equations.

The output variable - Schmookler's main emphasis - was expected to perform better than it did. The reason for this relative ineffectiveness could be that its effect may possibly be spread over time or perhaps felt more strongly with a lag. To investigate this possibility we re-estimated the model with a polynomial distributed lag specification. Those results are discussed in the next chapter.

CHAPTER FIVE: FOOTNOTES

1 In *"Research and Development in Industry 1975"*; NSF, Washington, D.C. 1976 net sales and receipts are defined as the "recorded dollar values for goods sold or services rendered by a company to customers outside the company, including the Federal Government, less such items as returns, allowances, freight charges, and excise taxes. Excludes domestic intracompany transfers as well as sales by foreign subsidiaries, but includes transfers to foreign subsidiaries."

2 *"Research and Development in Industry 1975"*; NSF, Washington, D.C., 1976, p. 14. That average ratio in our Table 5.6 is 0.0199 but then it does not include the years 1958-1962.

CHAPTER SIX

FURTHER RESULTS OF THE EMPIRICAL ESTIMATION

6.1. Introduction

In view of the results presented in Chapter Five, in which the relative wage rate variable had a more consistent effect on R&D expenditures than the output variable, the regressions were carried out using the polynomial distribution lag (PDL) technique. Our purpose was to find out whether there is any lag in the effect of output on R&D expenditure which might account for the relatively weak effect of current period output. While doing this it was natural to ask if the same was not true of the relative wage rate and the relative user cost variables as well. Therefore, the PDL estimation was extended to the relative factor price variables.

For each of the original equations two variants of the PDL regression were estimated. In one of them, only the output variable was allowed to affect R&D expenditures with a lag, while in the other both the relative factor price variables and the output variable were allowed to influence R&D expenditures with a lag. The PDL equations pertaining to the former are designated by PDL1 and the ones pertaining to the latter by PDL2 in the subsequent discussion. Both second and third degree polynomials were tried, but there was not much difference between the results. It seems that the lagged response for these variables can be described adequately by a second degree polynomial. The reported results conform to the second degree polynomial specification.

The results are presented in Tables 6.1 to 6.11 at the end of this chapter. The arrangement of tables follows the order of the previous chapter - starting with transportation equipment in the High R&D industries. For the sake of an easy comparison the results of the original estimation are re-reported. The very first column in each table identifies the results in the respective row as those for the original equation or the polynomial distributed lag (PDL) regression. The original equations are those that were discussed in the previous chapter. In each of the polynomial distributed lag equations, the lag in peak response is indicated by the number immediately following the t-statistic in the parenthesis appearing below the coefficient.

The maximum lag allowed for the output effect is based on the evidence presented in Schmookler (1966, p. 122). Analyzing the patent and output series for the Railroad industry for the period 1860-1950, he found that the output series led the patent series through peaks and troughs by a period varying to a maximum of five years. But output affects the number of patents through R&D expenditures and a lag is expected between the undertaking of R&D expenditures and the resulting patents. Therefore, in the preliminary investigation a lag of six years was allowed. On the other hand, for the relative price variables, in the absence of any prior evidence, the maximum possible lag permitted by the available data is allowed for. This is ten years for the estimation period starting with 1957 and six years for the estimation period, starting at year 1953.

For the following three industries, the results for the PDL equations allowing for both output and the relative factor price lag effects could not be estimated. This seems to be the result of some relative factor price variable coefficients attaining zero values. These industries are:

(i) Machinery;

(ii) Primary metals;

(iii) Fabricated metal products;

and the tables reporting results for these industries do not include PDL equations which allow a lagged reponse for both output and relative factor price variables. It should be pointed out that the PDL estimation reduces the degrees of freedom considerably. This is particularly true for the PDL equations where both output and the relative factor price variables are allowed for a lagged response. Therefore, the results can, at best, be interpreted as only suggestive.

6.2. Peak Response

In the PDL estimated equations when only the output is allowed to have a lagged effect, generally the peak response occurs without any time lag. More specifically, in all the High R&D industries there is no lag in the peak response. The output effect on R&D expenditures is instantaneous. This, however, is not the case in the Low R&D industries. The following Low R&D industries show a lagged peak response:

(i) Rubber and plastic products;

(ii) Primary metals;

(iii) Petroleum and coal products;

(iv) Fabricated metal products.

For the primary metals industry the lagged response occurs only when R&D price index Two is used in the specification. It should, however, be noticed that if we restrict the analysis to only those cases where the output coefficient remains significant in the PDL1 equations, the aforementioned list narrows down to only rubber and plastic products and the fabricated metal products industries. In the remaining two industries the output coefficients are insignificant in all the estimated PDL1 equations.

It should be recalled from the preceding chapter that the rubber and plastic products industry posed a dilemma with negative coefficients for the output variable.

The present evidence, presumably, explains why it was so. A look at Table 6.6 shows that the coefficient of output is positive and highly significant in all of the PDL1 estimated equations. Two of these equations show a peak response with a lag of two years; while the other two show a lag of one and three years. This evidence suggests that there is a lag in the response of R&D expenditures to output though it is not possible to be certain about the length of this lag. This evidence indicates the possibility that for this industry the demand equation without lags may be mis-specified, so that the negative output coefficent may very well be the result of a specification error.

In the fabricated metal products industry the output coefficient is significant in two out of four estimated PDL1 equations, both pertaining to the unit cost specification of the state of technology. They show a lag of three and four years in the peak response. Table 6.10 shows these results. It also shows that the output variable did not perform very well in the original analysis. The coefficient of output is significant in just one of four original equations. That poor performance seems to be the result of a lag in the effect of output on R&D expenditures in this industry as well.

As far as the relative factor price variables are concerned, no clear lag pattern with respect to the peak response is observed. In most of the PDL2 equations when the output and relative factor price variables allow for a lagged response, no coefficient remains significant. In the Low R&D set two industries (where the relative wage rate variable retained prime significance in the last chapter), only in the stone, clay, and glass products industry is a coefficient of relative wage rate significant, and this is in only one of the two PDL2 equations (estimation was possible with only R&D price index One). There is no lag in the peak response to this variable.

A lagged peak response to the relative factor price variables occurs in some of the High R&D industries. For example, in the transportation equipment, and the chemicals and allied products industries, Tables 6.1 and 6.4, respectively, one of the four PDL2 equations shows a lagged peak response for both the relative wage rate and the relative user cost variables. The peak response in the former lags by two years while the lag is three years in the latter. The PDL2 equations for the electrical and electronic equipment industry, Table 6.2, show that in two of these equations the peak response has a lag. In one of these equations only the relative user cost variable has a lagged response while in the other both the relative user cost and the relative wage rate have a lag in the peak response. The lag is five years in each of these cases. It is impossible, based on the evidence reported in this chapter, to draw a general conclusion that there is a lag in the effect of the relative factor price variables on R&D expenditures.

6.3. Some Additional Observations

This section is devoted to some additional observations with regard to the significance of the coefficients of different variables under PDL estimation. Starting with the PDL1 equations, it seems the coefficients most affected by the PDL estimation are the ones pertaining to the state of technology. Recall that the unit cost specification of the state of technology was not as successful as the alternative specification (the capital- and labour-output ratios) in the previous chapter. In none of the PDL1 equations is the unit cost variable significant. The alternative specification is less successful in the PDL1 regressions than in the unlagged version. In only three industries; electrical and electronic equipment, primary metals, and stone, clay, and glass products, are the coefficients of the capital- and labour-output ratio significant. These can be seen in Tables 6.2, 6.8, and 6.11, respectively.

The electrical and electronic equipment industry had the strongest results in the original analysis and it still retains that strength. In both the PDL1 equations pertaining to the capital- and labour-output ratios specification of the state of technology, the coefficients of both the capital- and labour-output ratio are significant.

In the primary metals industry, they are significant in only one of the estimated equations and this corresponds to R&D price index Two. For the stone, clay, and glass products industry, there is only one PDL equation for the capital- and labour-output ratios specification and in that equation both the coefficients are significant.

The relative wage rate coefficient generally remains significant in the corresponding PDL1 equations - that is, corresponding to the original equations where it was significant. There are a few expections however. These are: the machinery; the chemicals and allied products; and the stone, clay, and glass products industries. In the light of these results it would seem that although all variables were significant in the High R&D industries in the original estimation,output is significant more frequently in the PDL1 regressions. On the other hand, the relative wage rate variable was consistently significant in the Low R&D set two industries in the original estimation and it still retains that significance in the PDL1 regressions except for the case of the stone, clay, and glass products industry. In this industry its coefficient is close to significant with the t- statistic of 1.7285 in one of the two PDL1 equations, and insignificant in the other equation. Moreover, as noted previously, the capital- and labour-output ratio coefficients now become significant in this industry whereas they were insignificant in the original estimation. This could be taken as suggesting that the stone, clay, and glass products industry actually belongs to the Low R&D set one industries. In absence of any evidence with respect to R&D price index Two, this observation remains only tentative.

Notwithstanding these observations the capital- and labour-output ratio coefficients, which showed a consistent pattern in the Low R&D set one industries in the original analysis, fail to do so in the PDL estimation.

The PDL2 equations do not reveal any strong results. Generally all the coefficients are insignificant, perhaps because there are too few degrees of freedom. The coefficient which is significant more than others is the coefficient of the output variable.

In conclusion, considering the results analyzed in this chapter, the following suggestive remarks could be made:

(a) In the High R&D industries, R&D expenditures respond to output stimuli more consistently than to any other variable, but with no lag;

(b) In the Low R&D industries, R&D expenditures respond to relative wage rate change more consistently than to any other variable. Even here the results do not suggest the presence of any lagged effect.

Therefore, the specification of the model without lag response retains validity, and the results of the estimation presented in Chapter Five can be taken as reasonably reliable.

Table 6.1

Estimates of the Model with Polynomial Distrubuted Lag Regression for the Transportation Equipment Industry.

Estimation Period: 1957-1976

(11)

Procedure	Dependent variable	Constant	Independent variables							R^2	D-W statistic
			Y	w/PRD	q/PRD	$(K/Y)_{-1}$	$(L/Y)_{-1}$	C_{-1}	t		
Original equation	RD_1	0.7735 (0.2793)	0.3279 (2.7748)	0.4707 (1.5200)	-5.4057 (1.2986)	0.6364 (3.0946)	-0.3514 (3.3946)	-	0.0027 (1.2662)	0.9935	1.9525
PDL1	RD_1	1.1660 (0.4727)	0.6148 (3.2324)0	0.6776 (2.9244)	-1.9118 (0.6085)	0.3314 (1.3292)	-0.1824 (1.3827)	-	0.0007 (0.4736)	0.9974	2.6733
PDL2	RD_1	-29.5665 (0.8054)	0.7214 (1.6817)0	-2.2095 (0.6568)5	-58.6604 (0.8403)5	0.0275 (0.0341)	0.0111 (0.0251)	-	0.0095 (1.3950)	0.9955	3.3241
Original equation	RD_1	2.8467 (0.7974)	0.4630 (3.7915)	1.0174 (2.4808)	-1.3294 (0.2474)	-	-	0.0808 (1.5257)	0.0017 (0.7152)	0.9911	1.7481
PDL1	RD_1	-0.9406 (0.4681)	0.8514 (10.0757)0	0.6092 (2.5931)	-3.5182 (3.0343)	-	-	0.0224 (0.5775)	0.0009 (0.5453)	0.9970	2.5422
PDL2	RD_1	-23.3162 (0.9521)	0.7218 (3.4194)0	-1.5892 (0.6874)0	-46.9198 (0.9829)5	-	-	0.0642 (0.5278)	0.0086 (1.5636)	0.9955	3.3084
Original equation	RD_2	9.3525 (4.0316)	0.1341 (1.3169)	1.0903 (8.1779)	0.1801 (2.0768)	0.7737 (4.1260)	-0.4239 (4.4757)	-	0.0015 (0.8025)	0.9867	1.9488
PDL1	RD_2	4.2364 (1.4327)	0.4667 (2.0623)0	0.8822 (7.1986)	0.1846 (2.7344)	0.4779 (1.6900)	-0.2610 (1.7259)	-	0.0004 (0.2863)	0.9935	2.4944
PDL2	RD_2	-10.9025 (4.2674)	-0.0898 (0.1650)0	1.2662 (2.0495)2	-1.4252 (2.0184)2	-0.5150 (0.8155)	0.3102 (0.9101)	-	0.0073 (1.6590)	0.9932	3.1967
Original equation	RD_2	-1.4718 (0.3861)	0.4780 (4.8291)	0.8048 (3.9283)	-0.1039 (1.5869)	-	-	0.0544 (1.1419)	0.0011 (0.5370)	0.9756	1.8199
PDL1	RD_2	0.4076 (0.1850)	0.8323 (8.6428)0	0.8276 (6.1902)	0.1211 (2.1095)	-	-	0.0134 (0.3163)	0.0002 (0.1215)	0.9917	2.1175
PDL2	RD_2	-10.4587 (4.3009)	-0.1090 (0.2017)0	0.8423 (1.7508)2	-0.9439 (1.6949)2	-	-	-0.0933 (1.2239)	0.0053 (1.2325)	0.9909	1.4667

In Tables 6.1 through 6.11, the number immediately following the t-statistic (in parentheses) is the lag in the peak response.

Table 6.2

Estimates of the Model with Polynomial Distributed Lag Regression for the Electrical and Electronic Equipment Industry.

Estimation Period: 1957-1976

Procedure	Dependent variable	Constant	Independent variables							R^2	D-W statistic
			Y	w/PRD	q/PRD	$(K/Y)_{-1}$	$(L/Y)_{-1}$	C_{-1}	t		
Original equation	RD_1	3.8164 (4.8164)	0.3578 (4.9594)	1.0481 (3.8136)	1.0774 (0.6606)	0.6023 (5.8201)	-0.2721 (5.9541)	-	0.0018 (1.3017)	0.9975	1.1539
PDL1	RD_1	3.8571 (3.4426)	0.3461 (2.1407)0	1.0408 (3.6725)	1.1073 (0.6389)	0.6053 (2.6171)	-0.2806 (2.6204)	-	0.0027 (1.9163)	0.9981	2.1205
PDL2	RD_1	-5.8182 (1.2226)	0.4726 (3.7453)0	2.4535 (2.5575)0	15.7419 (2.0529)5	0.5356 (2.5371)	-0.2767 (2.7071)	-	0.0019 (1.2149)	0.9997	2.9444
Original equation	RD_1	3.0520 (1.9640)	0.7029 (10.3870)	1.2236 (2.4981)	0.0115 (0.0039)	-	-	0.0506 (0.9948)	0.0030 (1.1606)	0.9914	1.7967
PDL1	RD_1	2.3587 (1.9862)	0.7515 (16.0579)0	1.0455 (3.0164)	0.3172 (0.1487)	-	-	0.0171 (0.3077)	0.0038 (2.1692)	0.9969	1.7413
PDL2	RD_1	-6.6600 (1.1787)	0.7740 (12.6266)0	2.9470 (2.6161)0	15.3585 (1.6702)5	-	-	0.0645 (1.2481)	0.0041 (2.0911)	0.9994	1.6287
Original equation	RD_2	6.3403 (4.6151)	0.2927 (3.5745)	0.9839 (11.3477)	0.11989 (1.9517)	0.6469 (6.3842)	-0.2951 (6.4960)	-	0.0031 (2.0917)	0.9972	2.0455
PDL1	RD_2	4.9961 (2.7782)	0.3398 (2.0058)0	0.9140 (9.1405)	0.1210 (1.7692)	0.6037 (2.5823)	-0.2806 (2.5883)	-	0.0033 (2.1317)	0.9974	2.0180
PDL2	RD_2	-10.4729 (4.2421)	-0.0534 (0.1291)2	0.1401 (0.1393)5	-0.2299 (0.1970)5	0.9774 (1.4207)	-0.4533 (1.3466)	-	-0.0025 (0.6037)	0.9980	3.3804
Original equation	RD_2	3.0981 (1.2245)	0.7062 (7.7868)	1.1869 (7.0692)	-0.1899 (2.5003)	-	-	0.0505 (0.9207)	0.0030 (0.9870)	0.9887	1.7763
PDL1	RD_2	2.6478 (1.4097)	0.7501 (12.0399)0	1.0023 (8.3109)	0.0044 (0.0668)	-	-	0.0138 (0.3583)	0.0040 (2.0328)	0.9959	1.7031
PDL2	RD_2	-13.8571 (16.4632)	0.4831 (2.1491)2	1.2164 (2.0833)5	-1.4693 (2.1579)5	-	-	0.0838 (1.0027)	0.0009 (0.2660)	0.9971	2.9537

Table 6.3

Estimates of the Model with Polynomial Distributed Lag Regression for the Machinery Industry.

Estimation Period: 1957-1976

Procedure	Dependent variable	Constant	Independent variables							R^2	D-W statistic
			Y	w/PRD	q/PRD	$(K/Y)_{-1}$	$(L/Y)_{-1}$	C_{-1}	t		
Original equation	RD_1	37.9463 (3.0210)	0.3112 (4.9975)	1.5232 (8.4050)	20.3779 (2.6827)	0.6287 (7.0328)	-0.3522 (7.7840)	-	-0.0061 (5.9243)	0.9989	2.0007
PDL1	RD_1	-31.8031 (0.5819)	0.8013 (0.8420)[0]	0.2943 (0.3470)	-20.3295 (0.6075)	0.7703 (0.5328)	-0.4132 (0.5450)	-	-0.0034 (0.5862)	0.9754	0.8685
Original equation	RD_1	87.6690 (3.4027)	0.4537 (4.4945)	2.4747 (6.6703)	50.8784 (3.2628)	-	-	0.1690 (3.3248)	-0.0055 (2.3489)	0.9954	2.1471
PDL1	RD_1	-31.0358 (0.5862)	1.3407 (4.8684)[0]	0.4209 (0.5623)	-18.2703 (0.5660)	-	-	-0.0059 (0.0419)	-0.0045 (0.7426)	0.9747	0.7056
Original equation	RD_2	3.8989 (2.4101)	0.2231 (3.7662)	0.9469 (8.1022)	-0.0202 (0.4947)	0.7031 (6.5675)	-0.3860 (7.0665)	-	-0.0055 (4.3843)	0.9958	2.1306
PDL1	RD_2	2.4752 (0.2768)	0.8788 (0.7692)[0]	0.8626 (1.0294)	0.2094 (0.5993)	0.5513 (0.3208)	-0.2995 (0.3326)	-	-0.0047 (0.6025)	0.9110	0.8357
Original equation	RD_2	12.4075 (4.2005)	0.7964 (9.6038)	1.8288 (9.6912)	-0.2150 (2.9632)	-	-	0.1112 (2.2639)	-0.0111 (3.7754)	0.9821	1.8009
PDL1	RD_2	2.0488 (0.2395)	1.3020 (4.9038)[0]	1.0044 (1.8110)	0.1754 (0.8081)	-	-	-0.0085 (0.0601)	-0.0069 (0.9239)	0.9096	0.7856

Table 6.4

Estimates of the Model with Polynomial Distributed Lag Regression for the Chemicals and Allied Products Industry.

Estimation Period: 1957-1976

Procedure	Dependent variable	Constant	Independent variables: Y	w/PRD	q/PRD	$(K/Y)_{-1}$	$(L/Y)_{-1}$	C_{-1}	t	R^2	D-W statistic
Original equation	RD_1	6.1774 (12.9286)	0.0282 (0.2288)	1.0564 (4.8637)	-0.2115 (0.1285)	0.1173 (0.7203)	-0.0951 (0.8366)	-	-0.0016 (1.0658)	0.9976	1.8843
PDL1	RD_1	4.1192 (2.1111)	0.4923 $(0.9267)^{0}$	0.5271 (0.7108)	-3.0415 (0.5433)	0.1764 (0.2545)	-0.1342 (0.2785)	-	-0.0094 (1.8431)	0.9883	0.9668
PDL2	RD_1	2.7650 (0.6164)	0.6634 $(3.0459)^{0}$	1.7527 $(0.9230)^{4}$	15.8927 $(0.9496)^{4}$	0.0288 (0.0991)	0.0809 (0.4138)	-	-0.0045 (1.4037)	0.9994	3.0618
Original equation	RD_1	6.0801 (12.9631)	0.0829 (0.8330)	0.9192 (5.1419)	-1.1950 (0.9772)	-	-	-0.0280 (1.7254)	-0.0019 (1.6717)	0.9973	1.9464
PDL1	RD_1	3.5888 (5.2216)	0.6425 $(7.0519)^{0}$	0.3303 (0.6813)	-4.4584 (1.3393)	-	-	0.0238 (0.4559)	-0.0103 (3.1364)	0.9882	1.0207
PDL2	RD_1	2.6255 (0.7742)	0.7306 $(15.3490)^{0}$	-0.0684 $(0.7039)^{1}$	-8.3092 $(0.6145)^{0}$	-	-	0.0883 (1.9373)	-0.0010 (0.3808)	0.9988	2.8109
Original equation	RD_2	-6.9748 (3.2707)	0.2637 (2.0832)	0.2701 (1.8342)	0.0092 (0.1234)	0.2529 (1.4000)	-0.1838 (1.4549)	-	-0.0036 (1.6441)	0.9661	1.1905
PDL1	RD_2	-7.7359 (2.3621)	0.3240 $(1.8336)^{0}$	0.2171 (1.1251)	0.0367 (0.5015)	0.1834 (0.6790)	-0.1334 (0.6999)	-	-0.0040 (1.6393)	0.9710	1.4426
PDL2	RD_2	-15.6333 (3.1090)	1.3493 (1.2758)	-1.8546 (1.2060)	2.1873 (1.2172)	0.3364 (0.4586)	-0.2687 (0.5370)	-	-0.0060 (0.9646)	0.9865	2.2843
Original equation	RD_2	-7.3146 (3.2738)	0.4403 (8.6473)	0.3635 (2.6377)	-0.0509 (0.9579)	-	-	0.0087 (0.2576)	-0.0060 (3.1032)	0.9602	1.3114
PDL1	RD_2	-9.1225 (3.3922)	0.4333 $(7.5356)^{0}$	0.1921 (1.0620)	0.0110 (0.1938)	-	-	0.0158 (0.5068)	-0.0047 (1.9306)	0.9701	1.5252
PDL2	RD_2	-16.7980 (6.0314)	1.4743 $(2.3584)^{6}$	-1.6288 $(1.7918)^{3}$	1.9008 $(1.8008)^{3}$	-	-	0.1174 (0.1174)	-0.0060 (2.1070)	0.9902	2.6880

Table 6.5

Estimates of the Model with Polynomial Distributed Lag Regression for the Food and Kindred Products Industry.

Estimation Period: 1957-1975

Procedure	Dependent variable	Constant	Independent variables								D-W statistic
			Y	w/PRD	q/PRD	$(K/Y)_{-1}$	$(L/Y)_{-1}$	C_{-1}	t	R^2	
Original equation	RD_1	17.3266 (0.9393)	0.4797 (1.3894)	1.0632 (2.6310)	3.3689 (0.3611)	0.4787 (1.4748)	-2.2701 (1.8977)	-	0.0004 (0.1524)	0.9915	1.8331
PDL1	RD_1	4.7686 (0.3499)	1.4343 (3.0284)$_0$	1.2176 (5.8148)	3.7789 (0.6543)	-0.5592 (1.4114)	-0.1120 (0.1149)	-	-0.0004 (0.2000)	0.9963	2.6068
PDL2	RD_1	-60.7815 (0.7904)	1.3907 (0.8509)$_6$	-0.0002 (0.0001)$_5$	-40.2679 (0.7688)$_5$	-0.6968 (0.3423)	-0.2216 (0.1009)	-	0.0111 (1.3602)	0.9970	3.0150
Original equation	RD_1	-5.5474 (0.6381)	1.3564 (9.0510)	0.9653 (4.7153)	-1.0011 (0.1754)	-	-	-0.5056 (2.0180)	0.0052 (1.0684)	0.9899	1.7779
PDL1	RD_1	0.5384 (0.0600)	1.0662 (4.3287)$_0$	1.05158 (5.6506)	1.4978 (0.2844)	-	-	-0.1248 (0.4864)	-0.0015 (0.3631)	0.9954	2.0417
PDL2	RD_1	-30.0132 (0.6070)	0.7971 (1.8422)$_5$	0.3636 (0.4480)$_0$	-19.7510 (0.6118)$_5$	-	-	0.2143 (0.5052)	0.0092 (1.2427)	0.9964	2.8207
Original equation	RD_2	-0.4239 (0.0614)	0.5480 (2.0018)	0.4518 (1.5157)	0.0593 (0.7937)	0.5199 (1.8072)	-0.1488 (2.0043)	-	-0.0012 (0.4002)	0.9315	1.4634
PDL1	RD_2	-12.0271 (2.2193)	1.5624 (4.9926)$_0$	0.6363 (3.1943)	-0.0540 (0.9467)	-0.5031 (1.6544)	0.4761 (0.6599)	-	-0.0023 (1.1162)	0.9754	2.5299
PDL2	RD_2	-22.9130 (1.5474)	0.0340 (0.0063)$_0$	0.4470 (0.5246)$_2$	0.4226 (0.4860)$_2$	1.5610 (0.2988)	0.9040 (0.4891)	-	-0.0060 (1.0148)	0.9811	3.5078
Original equation	RD_2	-10.7991 (2.8644)	1.2594 (8.7727)	0.5545 (2.2514)	0.0017 (0.0368)	-	-	-0.5697 (2.7316)	-0.0077 (1.9823)	0.9253	1.9565
PDL1	RD_2	-10.4335 (3.5113)	1.1196 (6.2756)$_0$	0.4476 (2.6024)	0.0260 (0.7712)	-	-	0.0182 (0.0972)	-0.0025 (0.6936)	0.9686	1.9905
PDL2	RD_2	-22.3323 (4.8977)	1.9021 (2.3069)$_3$	-0.3640 (1.4623)$_2$	0.3908 (1.2805)$_2$	-	-	0.1088 (0.2199)	-0.0068 (0.9276)	0.9791	3.3993

Table 6.6

Estimates of the Model with Polynomial Distributed Lag Regression for the Rubber and Plastic Products Industry.

Estimation Period: 1957-1973

Procedure	Dependent variable	Constant	Independent variables								D-W statistic
			Y	w/PRD	q/PRD	$(K/Y)_{-1}$	$(L/Y)_{-1}$	C_{-1}	t	R^2	
Original equation	RD_1	0.2812 (0.0451)	-0.4845 (2.7168)	0.9652 (1.5344)	-3.6773 (0.2115)	0.7522 (3.0277)	0.7331 (2.6299)	-	-0.0081 (0.3564)	0.9973	1.8349
PDL1	RD_1	-26.0759 (3.4912)	3.6696 (6.9910)^{2}	-0.9395 (1.4205)	-56.3051 (3.0388)	-0.1652 (0.7720)	0.4879 (1.6977)	-	-0.2761 (5.8878)	0.9982	2.2047
PDL2	RD_1	70.9473 (1.5371)	-4.0120 (1.1037)^{1}	6.7283 (1.4414)^{0}	175.2600 (1.5269)^{0}	1.5547 (1.4170)	0.4876 (0.9170)	-	0.2674 (1.0627)	0.9997	3.2830
Original equation	RD_1	35.1901 (2.0980)	-0.4119 (0.9759)	4.0794 (2.5470)	83.2933 (1.8660)	-	-	0.6194 (1.7349)	0.0915 (2.3076)	0.9802	1.3467
PDL1	RD_1	27.2002 (3.1206)	4.0458 (7.0021)^{1}	-1.1700 (1.5015)	-62.5582 (2.9369)	-	-	0.1199 (0.7201)	-0.3114 (5.9907)	0.9976	2.5979
PDL2	RD_1	87.4010 (1.5317)	0.3175 (0.1160)^{5}	9.9815 (1.8206)^{0}	225.8980 (1.5925)^{0}	-	-	0.0507 (0.1437)	0.0002 (0.0008)	0.9988	3.1601
Original equation	RD_2	0.7451 (0.4838)	-0.4455 (3.6901)	0.9429 (7.6504)	-0.0481 (0.6945)	0.5644 (2.3345)	0.6582 (2.8216)	-	-0.0169 (0.7305)	0.9894	2.2011
PDL1	RD_2	6.4981 (1.9814)	2.7846 (4.8922)^{3}	0.7703 (2.4849)	0.0482 (0.2893)	0.0222 (0.0768)	0.3455 (0.8189)	-	-0.2069 (4.5373)	0.9877	1.7215
PDL2	RD_2	-24.8842 (0.9126)	9.2738 (0.5324)^{2}	1.9661 (0.3721)^{0}	-2.3946 (0.3852)^{0}	-1.4148 (0.2693)	-1.1654 (0.3989)	-	-0.7116 (0.5838)	0.9703	2.9207
Original equation	RD_2	0.6064 (0.2805)	-0.2470 (1.4529)	0.8327 (4.3132)	-0.0753 (0.6839)	-	-	0.0301 (0.1242)	0.0375 (1.5091)	0.9702	1.7512
PDL1	RD_2	-5.5731 (2.4238)	3.0289 (8.4183)^{2}	0.8232 (3.9882)	-0.0190 (0.1267)	-	-	-0.0498 (0.3397)	-0.2211 (6.8716)	0.9939	2.3684
PDL2	RD_2	-19.1257 (3.2459)	3.9586 (1.3289)^{4}	1.2225 (0.6255)^{3}	-1.4827 (0.6342)^{3}	-	-	-0.2380 (0.2632)	-0.3907 (1.4671)	0.9821	3.4690

Table 6.7

Estimates of the Model with Polynomial Distributed Lag Regression for the Paper and Allied Products Industry.

Estimation Period: For RD_1: 1953-1976
For RD_2: 1957-1976

Procedure	Dependent variable	Constant	Independent variables							R^2	D-W statistic
			Y	w/PRD	q/PRD	$(K/Y)_{-1}$	$(L/Y)_{-1}$	C_{-1}	t		
Original equation	RD_1	-62.3234 (1.6712)	1.1726 (2.4301)	0.0988 (0.1829)	-39.6518 (1.6797)	-0.0095 (0.0151)	-0.0112 (0.0303)	-	-0.0031 (0.7556)	0.9874	1.7832
PDL1	RD_1	-47.8701 (1.2183)	2.2878 (5.0863)0	0.3146 (0.6108)	-26.7936 (1.0683)	-0.8542 (1.3635)	0.5089 (1.4063)	-	-0.0041 (0.7778)	0.9901	1.6132
PDL2	RD_1	-51.4692 (0.5449)	1.2455 (1.5726)	-0.0554 (0.0409)	-31.5718 (0.5079)	0.9280 (0.8185)	-0.5225 (0.7675)	-	-0.0014 (0.1374)	0.9880	2.6467
Original equation	RD_1	-74.0055 (2.2130)	1.2239 (3.3929)	-0.0717 (0.1387)	-47.0918 (2.2172)	-	-	0.0985 (1.1765)	-0.0017 (0.4404)	0.9881	1.8080
PDL1	RD_1	-42.3956 (1.4322)	1.5818 (12.0654)0	0.3084 (0.7339)	-25.2358 (1.3022)	-	-	0.0947 (0.8280)	-0.00004 (0.0080)	0.9891	1.4432
PDL2	RD_1	-35.0487 (0.3802)	1.7131 (6.9216)0	0.3352 (0.2695)2	-19.8957 (0.3300)0	-	-	0.0566 (0.3470)	0.0007 (0.0655)	0.9865	2.3658
Original equation	RD_2	-2.5260 (0.8715)	0.2542 (0.6375)	0.5744 (2.7670)	0.1051 (0.7431)	0.9175 (1.8309)	-0.5389 (1.8238)	-	-0.0005 (0.1418)	0.9802	1.9424
PDL1	RD_2	-10.0094 (2.0701)	1.8957 (3.2718)0	0.3032 (0.9357)	0.4046 (1.8932)	0.1504 (0.1697)	-0.03011 (0.0581)	-	-0.0092 (2.0065)	0.9786	1.8928
PDL2	RD_2	-16.2367 (1.2915)	1.6051 (0.4746)4	-2.8949 (0.8028)1	3.4046 (0.8124)1	3.2125 (1.2028)	-1.9205 (1.1934)	-	-0.0110	0.9857	2.6188
Original equation	RD_2	-3.1652 (1.1393)	0.4485 (1.3332)	0.7703 (4.1474)	-0.0992 (1.0944)	-	-	0.0370 (0.4916)	-0.0009 (0.2412)	0.9756	1.8756
PDL1	RD_2	-8.1761 (1.8407)	1.7966 (9.4160)1	0.5080 (1.5771)	0.2671 (1.8370)	-	-	-0.0526 (0.4243)	-0.0056 (1.0199)	0.9724	1.4976
PDL2	RD_2	-19.4666 (1.6517)	1.7059 (0.5388)1	-0.5161 (0.1927)6	0.6076 (0.1971)6	-	-	-0.0348 (0.1157)	-0.0051 (0.3116)	0.9805	2.6196

Table 6.8

Estimates of the Model with Polynomial Distributed Lag Regression for the Primary Metals Industry

Estimation Period: 1957-1976

Procedure	Dependent variable	Constant	Independent variables								D-W statistic
			Y	w/PRD	q/PRD	$(K/Y)_{-1}$	$(L/Y)_{-1}$	C_{-1}	t	R^2	
Original equation	RD_1	-35.6153 (2.1625)	0.8247 (4.2332)	-0.0737 (0.2227)	-20.9175 (2.1227)	1.1026 (3.9767)	-0.6781 (3.9576)	-	-0.0168 (3.5055)	0.9752	1.7973
PDL1	RD_1	-31.0443 (1.3716)	0.6032 (0.7003)	-0.0517 (0.1475)	-18.7326 (1.5041)	1.2674 (1.2586)	-0.80261 (1.2293)		-0.0135 (2.4680)	0.9778	1.9432
Original equation	RD_1	-36.6144 (1.5789)	0.9736 (4.2129)	0.2573 (0.6071)	-21.7983 (1.5735)	-	-	0.1983 (1.3791)	-0.0044 (0.6554)	0.9517	1.4760
PDL1	RD_1	-53.9203 (2.8014)	1.3972 (5.1750)	-0.1627 (0.4541)	-30.7211 (2.6849)	-	-	0.1085 (0.8397)	-0.0057 (0.9863)	0.9751	1.7626
Original equation	RD_2	-8.1160 (2.8223)	0.0121 (0.0377)	0.0280 (0.1289)	0.2293 (2.2495)	0.7645 (2.9797)	-0.4810 (3.1104)	-	-0.0027 (0.3824)	0.5041	1.4679
PDL1	RD_2	-4.3794 (1.0789)	-0.9109 (1.2765)	-0.1784 (0.7133)	0.4073 (2.8986)	1.9494 (2.5937)	-1.2539 (2.5600)	-	-0.0030 (0.4793)	0.6207	2.0868
Original equation	RD_2	-11.4087 (3.7210)	-0.1438 (0.4483)	0.0278 (0.1172)	-0.0473 (0.7148)	-	-	0.2107 (2.0870)	0.0112 (1.6196)	0.3245	1.1409
PDL1	RD_2	-11.4457 (3.1246)	0.2760 (0.6188)	0.0595 (0.2179)	0.0501 (0.4740)	-	-	0.0942 (0.7451)	0.0076 (0.9743)	0.4016	1.1254

Table 6.9

Estimates of the Model with Polynomial Distributed Lag Regression for the Petroleum and Coal Products Industry

Estimation Period: 1957-1975

Procedure	Dependent variable	Constant	Independent variables							R^2	D-W statistic
			Y	w/PRD	q/PRD	$(K/Y)_{-1}$	$(L/Y)_{-1}$	C_{-1}	t		
Original equation	RD_1	5.5333 (2.9441)	0.0181 (0.0813)	0.9024 (7.8631)	-0.2812 (1.0261)	0.8425 (1.3489)	-1.2454 (2.5299)	-	-0.0052 (0.9528)	0.9970	1.4695
PDL1	RD_1	5.3736 (3.0299)	0.1045 (0.2537)$_2$	0.9437 (9.0397)	-0.2464 (0.9581)	0.3582 (0.3311)	-0.7993 (0.9928)	-	-0.0060 (1.0788)	0.9981	1.8299
PDL2	RD_1	-10.8820 (0.2048)	3.0449 (0.9032)	-0.3922 (0.2632)	-1.1661 (0.0451)	-1.7246 (0.4320)	-1.5548 (0.3902)	-	-0.0590 (0.5605)	0.9966	2.6669
Original equation	RD_1	2.3545 (1.5489)	0.5085 (1.9754)	0.9446 (8.7916)	-0.2125 (0.7142)	-	-	0.0277 (0.3781)	-0.0043 (0.7733)	0.9942	1.2676
PDL1	RD_1	3.0643 (1.7628)	0.2744 (0.9374)$_2$	0.9533 (7.6327)	-0.2217 (0.7245)	-	-	-0.1016 (1.5699)	-0.0088 (1.4494)	0.9970	0.9970
PDL2	RD_1	8.0311 (0.1782)	3.2832 (1.3639)$_3$	-0.0601 (0.0668)$_2$	9.4551 (0.3833)$_3$	-	-	-0.2262 (1.0571)	-0.1235 (1.1683)	0.9972	2.3918
Original equation	RD_2	4.0687 (1.0107)	-0.0745 (0.3864)	0.8437 (3.7779)	-0.0078 (0.3807)	0.4710 (0.9384)	-0.9448 (2.1261)	-	-0.0006 (0.1757)	0.7480	1.2611
PDL1	RD_2	8.0175 (1.9057)	-0.1491 (0.3805)$_6$	1.1133 (4.6060)	-0.0332 (1.3244)	0.5924 (0.4696)	-0.9923 (1.0639)	-	-0.0026 (0.7105)	0.8360	1.8196
PDL2	RD_2	-23.6752 (2.5983)	4.2944 (1.5929)$_0$	-1.7809 (1.4699)$_4$	1.9229 (1.4627)$_3$	-0.1366 (0.0589)	-0.3555 (0.1535)	-	-0.0680 (1.7798)	0.8703	3.3545
Original equation	RD_2	-1.6670 (0.6488)	0.3723 (3.9835)	0.6984 (4.2710)	-0.0179 (1.5410)	-	-	0.1078 (2.2976)	-0.0006 (0.2252)	0.8095	1.8191
PDL1	RD_2	8.2773 (1.5362)	0.0393 (0.2393)$_2$	1.2900 (3.8507)	-0.0432 (1.8453)	-	-	-0.1514 (1.7770)	-0.0078 (1.7506)	0.7608	1.1703
PDL2	RD_2	-24.1110 (3.6789)	3.8015 (1.9092)$_0$	-1.5824 (1.6016)$_3$	1.6844 (1.5726)$_3$	-	-	0.0794 (0.6059)	-0.0539 (1.7013)	0.8754	3.3576

Table 6.10

Estimates of the Model with Polynomial Distributed Lag Regression for the Fabricated Metal Products Industry

Estimation Period: 1957-1976

Procedure	Dependent variable	Constant	Independent variables							R^2	D-W statistic
			Y	w/PRD	q/PRD	$(K/Y)_{-1}$	$(L/Y)_{-1}$	C_{-1}	t		
Original equation	RD_1	9.4901 (0.6559)	-0.0427 (0.1864)	1.1013 (2.8790)	4.4452 (0.3838)	0.6297 (1.6910)	-0.2993 (1.8183)	-	0.0017 (0.5273)	0.9847	2.2401
PDL1	RD_1	4.68324 (0.2333)	0.2043 (0.2692)[3]	1.0387 (2.2659)	1.3656 (0.0971)	0.2864 (0.2736)	-0.1366 (0.2809)	-	0.0025 (0.6925)	0.9856	2.2722
Original equation	RD_1	-2.8921 (0.2057)	0.3314 (2.9211)	0.9934 (2.3996)	-4.8209 (0.4202)	-	-	0.0601 (0.7602)	0.0012 (0.3229)	0.9805	2.2445
PDL1	RD_1	1.9450 (0.1347)	0.4325 (3.5192)[3]	1.0165 (2.3980)	-0.0452 (0.0038)	-	-	-0.0093 (0.1148)	0.0018 (0.4897)	0.9854	2.3022
Original equation	RD_2	-2.8497 (1.5098)	-0.0696 (0.5150)	0.5967 (4.3780)	-0.0562 (0.5686)	0.3445 (1.4491)	-0.1766 (1.6672)	-	0.0023 (1.0872)	0.7580	1.9539
PDL1	RD_2	-6.5409 (2.5070)	0.5165 (1.3982)[4]	0.6415 (5.0630)	-0.1670 (1.5637)	-0.4688 (0.8957)	0.2101 (0.8575)	-	0.0024 (1.2101)	0.8385	2.9379
Original equation	RD_2	-4.2707 (2.3403)	0.1087 (1.2043)	0.6731 (4.9549)	-0.1813 (2.9064)	-	-	0.0716 (1.3546)	0.0017 (0.6756)	0.6956	1.7524
PDL1	RD_2	-4.7973 (3.0952)	0.2113 (2.3901)[4]	0.5878 (5.1653)	-0.0872 (1.3190)	-	-	0.0268 (0.5641)	0.0027 (1.3315)	0.8244	2.5586

Table 6.11

Estimates of the Model with Polynomial Distributed Lag Regression for the Stone, Clay, and Glass Products Industry

Estimation Period: 1953-1976

Procedure	Dependent variable	Constant	Independent variables								D-W statistic
			Y	w/PRD	q/PRD	$(K/Y)_{-1}$	$(L/Y)_{-1}$	C_{-1}	t	R^2	
Original equation	RD_1	2.1416 (0.1237)	-0.0574 (0.2727)	1.0192 (3.0580)	-1.4472 (0.1320)	-0.1711 (0.3650)	0.0714 (0.2819)	-	-0.0039 (1.4162)	0.9833	1.9790
PDL1	RD_1	6.7117 (0.2361)	0.0971 (0.2446)$_0$	0.8202 (1.7285)	2.5564 (0.1418)	1.1104 (2.3293)	-0.5824 (2.3150)	-	-0.0058 (0.8850)	0.9652	1.3078
PDL2	RD_1	-14.0566 (0.6134)	1.6773 (3.2175)$_1$	0.9035 (2.2293)$_0$	-7.0137 (0.4733)$_0$	-1.6873 (2.1533)	0.8928 (2.1508)	-	0.0031 (0.6835)	0.9918	2.0706
Original equation	RD_1	-6.3049 (0.3782)	-0.0817 (0.4282)	0.8502 (2.7409)	-6.8738 (0.6499)	-	-	0.1164 (1.7769)	-0.0018 (0.6003)	0.9848	1.9217
PDL1	RD_1	-43.2041 (1.4778)	0.7990 (3.8158)$_0$	0.1407 (0.2813)	-27.7903 (1.4584)	-	-	0.1865 (1.0581)	0.0032 (0.3752)	0.9557	0.7945
PDL2	RD_1	-18.8200 (0.6763)	0.5525 (2.9594)$_1$	0.5277 (1.1537)$_0$	-12.6370 (0.7022)$_0$	-	-	0.0623 (0.5139)	0.0041 (0.6949)	0.9875	2.0058

CHAPTER SEVEN

CONCLUSION

The purpose of the present study was to explore the role of different variables in determining the rate of inventive activity in several manufacturing industries in the United States. More specifically, it was an attempt to learn the effects of the demand for and the supply of inventive activity in determining R&D expenditures (inventive effort) in those industries. This, it was hoped, would help in a better understanding of the role of these forces in inventive activity, a subject which has been a matter of active debate in recent years. Had it not been for the specific nature of inventive activity, the question of whether the supply of or the demand for a good is more important would hardly have become a matter of debate. Generally, both supply and demand are governed by economic forces. But this is not obvious in the case of inventive activity. The relative importance of the two factors (demand and supply) has significant policy implications.

The supply of inventive activity is considered to be governed by non-economic forces and thus exogenous to the economic system. For example, it is hard to concede that economic forces have much to do with the supply of inventive genius - a primary focus of inventive activity in the transcendentalist approach. This explains why the subject of inventive activity retained only a peripheral status in the discipline of economics until very recently. On the other hand, the demand for inventive activity, from the mechanistic approach of the Chicago sociologists to the recent attempts by the economists, has been considered to be mostly affected by economic forces.

Depending on which of the two forces (demand or supply) is more important in affecting the rate of inventive activity, different policy prescriptions will be appropriate. If the supply of inventive activity is considered to determine its rate, market forces could not be relied upon to provide for the required inventive activity in a perfectly competitive economic system. Provision of inventive activity would call for public policy initiative to facilitate the work of would-be inventors.[1] If, however, the demand for inventive activity is assumed to determine its rate, the market mechanism could be relied upon for the provision of inventive activity.

A model of induced technological change was developed in Chapter Three which provided a framework for the empirical analysis of Chapters Five and Six. The model sought to make explicit the effect of demand and supply variables on R&D expenditures. The model included output, relative factor prices, and the state of technology in an industry as the demand side variables. The state of knowledge, represented by a time trend, was included to capture the supply side effect.

The empirical evidence presented in Chapters Five and Six indicates that demand has been a significant determinant of the rate of inventive activity. The role of final product demand has been emphasized by other researchers in the past. The present evidence shows that in addition to final product demand measured by output, relative factor prices have an important effect. In fact, the results indicate that relative factor prices may be even more important in determining the rate of inventive activity than the final demand for output. This result is consistent with Nadiri's (1979) evidence which also shows that relative factor prices are important in determining R&D expenditures.

In addition to output and relative factor prices, which emerge as the more significant determinants, the state of technology also affects R&D expenditures in the industries studied. Thus, our results suggest that market forces do play an important role in determining inventive activity.

These general conclusions need to be qualified in the following way: The evidence also shows that the model explains inventive activity better in the High R&D industries than in the Low R&D industries, where the output variable performed questionably. There are only four High R&D industries out of the 11 industries studied. This would lead one to believe that the model and the output variable, in particular, does not explain inventive activity well when the entire manufacturing sector is considered. This, however, is not necessarily true. If, instead of looking at the number of industries, one considers the size of inventive activity in the entire manufacturing sector the output variable performs relatively better. This is because the High R&D industries, on average, account for almost two-thirds of total private R&D expenditures. And in those industries the model explains inventive activity reasonably well, and the output variable has a significant impact.

A second qualification to the results is the question raised by Professor Williams (1973, p. xv): "The impact of R&D in one industry may have a substantial effect on productivity in other industries". There might be an inter-industry flow of technology which the present model does not capture. Thus, it is possible that the higher degree of inventive activity in the High

R&D industries is a partial substitute for inventive activity in the Low R&D industries. The Low R&D industries may get their technology from the High R&D industries. This may be true particularly since the High R&D industries include the capital goods industries such as machinery, and electrical and electronic equipment.

If that is the case it raises another pertinent question. If the High R&D industries account for the supply of inventive activity to the Low R&D industries, the relationship and the interaction between supply and demand forces may be much more complicated than the present model assumes. This may explain why the state of knowledge (the supply side of inventive activity) variable did not perform very well in the empirical estimates. In this respect, as early as 1962, Nelson (1962, p. 12) wrote: "It is clear that some industries are much more R and D intensive than others but the reasons are not apparent".

The answer to this query, in light of the above discussion, may very well reside in Schmookler's argument that the supply side of inventive activity only determines which industries the inventions are carried out by (see p. 22 above). He argued that in view of the "highly flexible, multipurpose knowledge base amenable to development at virtually all points" (Schmookler, 1966, p. 173), the supply side determines which industries are most efficient in providing the innovations. Thus, if electrical machines are cheaper to produce than mechanical ones, the demand for machines will be satisfied by the electrical machinery industry. In that case one would expect the supply side to emerge as a significant determinant of inventive activity in the High R&D industries. But that is not true as far as the present evidence is concerned. In both High and Low R&D industries the effect of the supply side remains ambiguous. That lends additional support to the corollary that the present model is deficient in capturing the complex supply side effect. Therefore, the inter-relation between supply and demand forces along with the inter-industry substitution of inventive activity need to be studied in more detail.

Another issue highlighted by the present empirical evidence pertains to the relationship between private and public R&D expenditures. Most of the public R&D effort is concentrated in the High R&D industries. This may suggest that the public effort enhances the private inventive effort. If that is the case, then the public outlay on R&D should be included in the model as an independent variable influencing private R&D expenditures. In this respect, the evidence presented by Howe and McFetridge (1976, p. 68) is not very convincing as they conclude:

> "we have found that despite the requirement that recipients of R&D incentive grants match public funds with their own, the over-all commitment of resources to R&D by recipients of grants increased in only one of the three industries studied."

On the other hand, it is also possible that private inventive effort guides the allocation, if not the magnitude, of public R&D expenditures. If this is true market forces would seem to play an important role in directing public inventive effort. Considering its significance for policy this question needs to be explored further.

The present study, though it highlights the role of demand side forces in determining the rate of inventive activity, leaves a number of important questions unanswered. Nevertheless, by taking the individual industry characteristics into consideration it serves a useful purpose of pinpointing those areas which need to be explored further and raises questions which deserve immediate attention. Thus, it would seem that; a) the effect of relative factor prices on the inventive activity should be put to additional empirical investigation; b) the effect of the supply of inventive activity and its interaction with the demand in different industries as well as the inter-industry transfer of technology should be further investigated and, c) the relationship between public and private inventive effort should be subjected to additional scrutiny.

CHAPTER SEVEN: FOOTNOTES

[1] This argument differs from the argument for public regulation on the basis of a divergence between the social and the private returns to inventive activity as suggested by Arrow (1962).

APPENDIX

Abbreviations

Bldg.	Building
Cap.	Capital
Dep'n.	Depreciation
Equip.	Equipment

Table A.1a

Estimated Capital Stock, Depreciation Rate, and Amount of Depreciation for the Food and Kindred Products Industry, 1949-1976

Year	Bldg. Cap. Stock	Equip. Cap. Stock	Total Cap. Stock	Bldg. Cap. Dep'n. Rate	Equip. Cap. Dep'n. Rate	Bldg. Cap. Dep'n.	Equip. Cap. Dep'n.
1949	2051.08	3925.14	5976.22	.0220	.0651	40.64	227.31
1950	2254.47	4213.98	6468.45	.0258	.0714	47.21	263.57
1951	2723.19	4664.62	7387.81	.0280	.0767	58.30	310.40
1952	2875.82	4766.34	7642.16	.0258	.0764	65.24	344.21
1953	3042.26	4891.35	7933.62	.0252	.0791	70.09	374.54
1954	3156.05	5177.53	8333.58	.0249	.0845	73.02	410.34
1955	3355.35	5415.94	8771.30	.0266	.0901	79.78	452.69
1956	3796.20	5916.36	9712.56	.0285	.0994	91.72	523.05
1957	4120.55	6362.58	10483.14	.0279	.1035	101.37	598.44
1958	4231.72	6483.84	10715.56	.0267	.1034	105.44	649.55
1959	4433.88	6705.46	11139.33	.0277	.1095	112.34	706.68
1960	4563.49	6786.35	11349.84	.0277	.1155	117.94	765.60
1961	4668.12	6743.92	11412.04	.0281	.1193	123.42	810.92
1962	4926.72	6790.96	11717.68	.0286	.1270	129.75	860.94
1963	5193.18	6802.84	11996.02	.0296	.1358	138.97	918.14
1964	5508.98	6886.62	12395.60	.0300	.1440	149.18	980.50
1965	5865.22	6950.78	12816.01	.0307	.1534	161.55	1049.93
1966	6374.55	7540.44	13914.99	.0315	.1159	177.69	802.82
1967	6923.22	8145.22	15068.45	.0319	.1216	195.37	861.29
1968	7539.64	8747.94	16287.58	.0324	.1204	215.74	932.14
1969	8453.32	9360.12	17813.44	.0336	.1183	244.19	997.88
1970	9551.15	10113.58	19664.74	.0343	.1205	278.87	1086.43
1971	10549.07	11002.95	21552.02	.0343	.1228	314.81	1192.45
1972	11435.63	11748.57	23184.20	.0340	.1203	348.02	1271.15
1973	12585.23	12400.24	24985.47	.0349	.1194	390.46	1346.57
1974	15199.87	14107.62	29307.49	.0386	.1266	477.34	1514.02
1975	17506.22	16952.52	34458.73	.0379	.1353	563.16	1816.12
1976	18394.81	18786.81	37181.62	.0347	.1252	599.25	2018.98

Table A.1b

Estimated Real Capital Stock, and User Cost of Capital for the Food and Kindred Products Industry, 1949-1976

Year	Real Bldg. Cap. Stock	Real Equip. Cap. Stock	Total Real Cap. Stock	User Cost of Bldg. Cap.	User Cost of Equip. Cap.	User Cost of Total Cap.
1949	20.68	37.14	57.83	5.30	3.65	4.24
1950	22.36	38.70	61.06	3.29	7.09	5.70
1951	24.10	40.06	64.15	-6.13	4.37	.43
1952	24.94	40.34	65.29	3.79	10.49	7.93
1953	25.92	40.62	66.54	4.35	10.80	8.29
1954	27.33	41.88	69.21	7.69	10.38	9.32
1955	28.49	43.08	71.57	4.21	12.82	9.39
1956	29.73	44.08	73.81	-2.35	8.96	4.41
1957	30.97	44.64	75.61	2.95	11.38	7.93
1958	32.36	44.84	77.19	10.24	17.83	14.65
1959	33.74	45.36	79.10	8.37	18.99	14.46
1960	35.00	45.27	80.27	9.88	21.25	16.29
1961	36.03	45.04	81.08	9.51	23.88	17.50
1962	37.85	45.24	83.09	8.25	24.62	17.16
1963	39.58	45.21	84.79	8.10	26.08	17.68
1964	41.40	45.48	86.88	7.66	27.15	17.86
1965	43.08	45.62	88.70	6.81	28.84	18.14
1966	44.84	48.59	93.43	5.11	22.38	14.09
1967	46.67	51.11	97.78	5.73	22.96	14.73
1968	48.46	53.01	101.47	5.98	22.86	14.80
1969	50.45	55.02	105.47	3.87	25.40	15.10
1970	52.53	57.28	109.81	3.97	26.48	15.71
1971	54.09	59.64	113.72	4.67	25.30	15.49
1972	55.35	62.15	117.50	7.08	28.84	18.59
1973	56.40	64.44	120.84	5.33	31.71	19.39
1974	57.70	67.72	125.42	-11.69	25.05	8.15
1975	58.47	71.17	129.65	-3.71	18.98	8.75
1976	59.55	74.61	134.16	22.15	34.98	29.29

Table A.2a

Estimated Capital Stock, Depreciation Rate, and Amount of Depreciation for the Lumber and Wood Products Industry, 1949-1976

Year	Bldg. Cap. Stock	Equip. Cap. Stock	Total Cap. Stock	Bldg. Cap. Dep'n. Rate	Equip. Cap. Dep'n. Rate	Bldg. Cap. Dep'n.	Equip. Cap. Dep'n.
1949	488.20	1158.57	1646.77	.0220	.1321	10.17	150.21
1950	535.98	1166.17	1702.14	.0246	.1403	11.25	168.57
1951	656.44	1218.56	1875.01	.0280	.1668	13.87	199.12
1952	698.03	1148.93	1846.97	.0262	.1793	15.73	223.66
1953	746.75	1055.81	1802.55	.0254	.1984	17.01	245.31
1954	786.02	982.43	1768.44	.0252	.2293	17.90	268.55
1955	872.67	924.66	1797.33	.0270	.2715	19.81	294.30
1956	1005.49	867.66	1873.14	.0295	.3439	23.67	343.57
1957	1072.20	890.44	1962.64	.0281	.1945	26.59	191.99
1958	1117.63	892.55	2010.18	.0260	.2137	27.25	196.89
1959	1184.68	920.82	2105.50	.0279	.2226	29.41	201.11
1960	1245.44	963.46	2208.89	.0278	.2226	31.18	203.06
1961	1269.32	920.96	2190.28	.0283	.2252	33.22	210.28
1962	1317.57	925.57	2243.13	.0281	.2200	34.83	211.72
1963	1420.90	979.25	2400.16	.0289	.2314	36.83	213.66
1964	1491.07	1041.90	2532.98	.0303	.2319	40.27	215.22
1965	1588.02	1197.73	2785.75	.0300	.2222	43.26	218.95
1966	1706.05	1361.45	3067.50	.0312	.2365	47.61	248.00
1967	1816.53	1456.93	3273.46	.0313	.2287	51.90	279.01
1968	1933.40	1604.22	3537.62	.0317	.2171	56.48	303.45
1969	2135.37	1796.42	3931.78	.0330	.2195	62.86	331.22
1970	2355.34	1909.60	4264.94	.0341	.2299	71.00	380.28
1971	2588.67	2150.88	4739.55	.0340	.2253	78.76	420.10
1972	2882.69	2445.25	5327.94	.0343	.2318	86.75	462.52
1973	3214.57	2724.80	5939.37	.0362	.2347	99.14	517.26
1974	3970.30	3410.37	7380.67	.0393	.2406	122.29	598.87
1975	4573.74	4193.78	8767.52	.0386	.2582	146.48	761.46
1976	4786.73	4564.08	9350.81	.0346	.2251	155.90	877.74

Table A.2b

Estimated Real Capital Stock, and User Cost of Capital for the Lumber and Wood Products Industry, 1949-1976

Year	Real Bldg. Cap. Stock	Real Equip. Cap. Stock	Real Total Cap. Stock	User Cost of Bldg. Cap.	User Cost of Equip. Cap.	User Cost of Total Cap.
1949	4.92	10.96	15.89	5.30	10.73	9.05
1950	5.32	10.71	16.03	3.16	14.59	10.80
1951	5.81	10.46	16.27	-6.13	14.85	7.37
1952	6.05	9.72	15.78	3.83	22.65	15.43
1953	6.36	8.77	15.13	4.36	25.16	16.42
1954	6.81	7.95	14.75	7.71	28.29	18.80
1955	7.41	7.36	14.77	4.25	35.62	19.88
1956	7.87	6.46	14.34	-2.21	41.79	17.62
1957	8.06	6.25	14.31	2.98	24.35	12.31
1958	8.55	6.17	14.72	10.16	33.78	20.07
1959	9.02	6.23	15.24	8.39	35.71	19.56
1960	9.55	6.43	15.98	9.88	37.29	20.91
1961	9.80	6.15	15.95	9.54	39.74	21.19
1962	10.12	6.17	16.29	8.18	38.58	19.69
1963	10.83	6.51	17.34	8.00	40.46	20.19
1964	11.21	6.88	18.09	7.70	40.46	20.16
1965	11.66	7.86	19.52	6.72	39.32	19.85
1966	12.00	8.77	20.77	5.07	41.11	20.29
1967	12.25	9.14	21.39	5.64	40.01	20.33
1968	12.43	9.72	22.15	5.87	38.82	20.33
1969	12.74	10.56	23.30	3.77	42.62	21.37
1970	12.95	10.82	23.77	3.93	45.81	22.98
1971	13.27	11.66	24.93	4.60	44.23	23.13
1972	13.95	12.94	26.89	7.16	49.92	27.73
1973	14.41	14.16	28.57	5.60	53.89	29.53
1974	15.07	16.37	31.44	-11.53	48.80	19.88
1975	15.28	17.61	32.88	-3.50	48.25	24.21
1976	15.50	18.13	33.62	22.11	60.14	42.61

Table A.3a

Estimated Capital Stock, Depreciation Rate, and Amount of Depreciation for the Paper and Allied Products Industry, 1949-1976

Year	Bldg. Cap. Stock	Equip. Cap. Stock	Total Cap. Stock	Bldg. Cap. Dep'n. Rate	Equip. Cap. Dep'n. Rate	Bldg. Cap. Dep'n.	Equip. Cap. Dep'n.
1949	496.30	1678.09	2174.39	.0220	.0756	9.79	109.95
1950	556.05	1833.58	2389.63	.0259	.0857	11.42	131.73
1951	709.87	2136.11	2845.98	.0285	.0919	14.37	158.94
1952	776.15	2296.49	3072.64	.0272	.0946	16.94	185.50
1953	858.75	2486.26	3345.02	.0260	.0978	18.81	212.00
1954	954.73	2711.69	3666.42	.0258	.1042	20.42	243.91
1955	1055.75	2952.00	4007.75	.0281	.1086	23.76	277.31
1956	1294.34	3467.64	4761.98	.0291	.1204	28.32	332.11
1957	1524.17	3984.66	5508.83	.0294	.1275	33.63	401.89
1958	1598.52	4064.95	5663.47	.0279	.1246	37.61	458.83
1959	1702.51	4201.38	5903.89	.0273	.1247	40.87	504.18
1960	1777.26	4237.19	6014.44	.0271	.1326	43.57	551.17
1961	1825.78	4138.70	5964.48	.0274	.1381	46.20	588.17
1962	1922.74	4136.99	6059.72	.0276	.1477	48.79	625.13
1963	2004.60	4223.01	6227.61	.0285	.1239	52.24	514.09
1964	2126.96	4467.80	6594.76	.0287	.1288	55.65	534.10
1965	2316.26	4884.11	7200.36	.0297	.1336	60.35	567.93
1966	2604.84	5526.25	8131.09	.0311	.1371	67.64	616.31
1967	2943.54	6269.94	9213.48	.0316	.1383	76.48	688.20
1968	3243.58	6714.87	9958.45	.0321	.1362	87.23	772.70
1969	3656.95	7249.70	10906.65	.0323	.1279	99.78	830.25
1970	4074.86	7799.57	11874.44	.0328	.1300	114.61	900.10
1971	4427.09	8198.87	12625.96	.0323	.1282	128.22	964.76
1972	4747.05	8542.33	13289.39	.0321	.1222	140.16	995.95
1973	5171.11	8974.34	14145.45	.0333	.1251	156.11	1050.93
1974	6242.76	10416.47	16659.23	.0370	.1363	189.54	1185.08
1975	7218.33	12831.40	20049.73	.0366	.1492	223.67	1449.27
1976	7510.65	14621.34	22131.99	.0336	.1387	238.73	1651.74

Table A.3b

Estimated Real Capital Stock, and User Cost of Capital for the Paper and Allied Products Industry, 1949-1976

Year	Real Bldg. Cap. Stock	Real Equip. Cap. Stock	Total Real Cap. Stock	User Cost of Bldg. Cap.	User Cost of Equip. Cap.	User Cost of Total Cap.
1949	5.00	15.88	20.88	5.30	4.75	4.89
1950	5.51	16.84	22.35	3.30	8.64	7.32
1951	6.28	18.34	24.63	-6.07	6.14	3.02
1952	6.73	19.44	26.17	3.95	12.64	10.41
1953	7.32	20.65	27.96	4.43	13.05	10.79
1954	8.27	21.93	30.20	7.79	12.82	11.44
1955	8.96	23.48	32.45	4.38	15.15	12.17
1956	10.14	25.84	35.97	-2.27	11.79	7.83
1957	11.45	27.96	39.41	3.15	14.80	11.42
1958	12.22	28.11	40.33	10.41	20.90	17.72
1959	12.96	28.42	41.38	8.31	21.24	17.19
1960	13.63	28.27	41.90	9.80	23.82	19.25
1961	14.09	27.64	41.74	9.42	26.70	20.86
1962	14.77	27.56	42.33	8.12	27.72	20.88
1963	15.28	28.07	43.34	7.95	24.28	18.53
1964	15.99	29.51	45.49	7.48	24.84	18.74
1965	17.01	32.06	49.07	6.67	25.83	19.19
1966	18.32	35.61	53.93	5.05	25.67	18.67
1967	19.84	39.35	59.19	5.69	25.61	18.93
1968	20.85	40.69	61.54	5.93	25.47	18.85
1969	21.82	42.61	64.44	3.65	27.03	19.11
1970	22.41	44.18	66.59	3.69	28.17	19.93
1971	22.70	44.44	67.14	4.27	26.31	18.86
1972	22.98	45.19	68.16	6.69	29.21	21.62
1973	23.17	46.63	69.81	4.96	32.80	23.55
1974	23.70	50.00	73.70	-12.14	27.07	14.46
1975	24.11	53.87	77.98	-4.08	22.29	14.14
1976	24.32	58.07	82.38	21.83	38.38	33.50

Table A.4a

Estimated Capital Stock, Depreciation Rate, and Amount of Depreciation for the Chemicals and Allied Products Industry, 1949-1976

Year	Bldg. Cap. Stock	Equip. Cap. Stock	Total Cap. Stock	Bldg. Cap. Dep'n. Rate	Equip. Cap. Dep'n. Rate	Bldg. Cap. Dep'n.	Equip. Cap. Dep'n.
1949	1302.38	3245.04	4547.43	.0220	.0961	25.80	281.27
1950	1443.30	3467.26	4910.56	.0258	.1067	29.98	330.29
1951	1877.66	4101.19	5978.85	.0282	.1188	37.31	397.34
1952	2186.09	4531.81	6717.90	.0277	.1284	44.79	476.05
1953	2461.80	4858.14	7319.94	.0275	.1355	52.73	563.65
1954	2624.59	5095.15	7719.74	.0262	.1415	58.21	653.62
1955	2844.98	5052.92	7897.90	.0269	.1474	65.24	734.96
1956	3298.21	5430.22	8728.43	.0285	.1628	76.37	843.59
1957	3688.68	5889.03	9577.72	.0280	.1818	86.29	980.73
1958	3808.48	5719.17	9527.65	.0268	.1902	92.19	1096.76
1959	3975.04	5502.43	9477.47	.0272	.2007	98.76	1199.28
1960	4128.58	5660.90	9789.48	.0270	.1533	103.43	895.99
1961	4247.26	5728.87	9976.13	.0277	.1663	109.13	927.93
1962	4400.26	5878.49	10278.76	.0281	.1706	115.32	964.81
1963	4668.28	6109.49	10777.76	.0285	.1697	121.79	974.62
1964	5013.56	6608.46	11622.02	.0296	.1682	131.50	991.03
1965	5527.42	7586.93	13114.34	.0304	.1688	143.89	1037.64
1966	6255.36	8826.26	15081.62	.0317	.1734	162.76	1152.96
1967	6993.25	10015.87	17009.11	.0320	.1713	184.86	1324.02
1968	7125.12	10948.55	18073.67	.0320	.1641	209.00	1487.25
1969	8155.95	11816.52	19972.48	.0307	.1549	225.10	1606.95
1970	9276.86	12909.47	22186.33	.0340	.1573	261.29	1775.84
1971	10281.26	13812.67	24093.92	.0335	.1622	296.68	1988.75
1972	11060.44	14241.61	25302.04	.0331	.1587	329.01	2140.93
1973	12193.59	14800.06	26993.66	.0337	.1603	367.28	2268.64
1974	14862.53	17606.06	32468.59	.0376	.1773	449.73	2570.03
1975	17316.76	22324.18	39640.94	.0371	.1997	534.24	3198.99
1976	18304.49	26030.42	44334.91	.0339	.1828	573.20	3680.58

Table A.4b

Estimated Real Capital Stock, and User Cost of Capital for the Chemicals and Allied Products Industry, 1949-1976

Year	Real Bldg. Cap. Stock	Real Equip. Cap. Stock	Total Real Cap. Stock	User Cost of Bldg. Cap.	User Cost of Equip. Cap.	User Cost of Total Cap.
1949	13.13	30.71	43.84	5.30	6.92	6.44
1950	14.31	31.84	46.16	3.29	10.93	8.56
1951	16.61	35.22	51.83	-6.10	9.27	4.34
1952	18.96	38.36	57.32	4.01	16.63	12.46
1953	20.98	40.34	61.32	4.61	17.58	13.15
1954	22.72	41.21	63.94	7.83	17.43	14.02
1955	24.16	40.20	64.35	4.24	20.01	14.09
1956	25.83	40.46	66.29	-2.34	17.48	9.76
1957	27.72	41.32	69.04	2.97	22.54	14.68
1958	29.12	39.55	68.67	10.27	30.38	21.85
1959	30.25	37.22	67.47	8.31	32.47	21.64
1960	31.67	37.76	69.43	9.78	26.91	19.10
1961	32.79	38.26	71.05	9.46	30.93	21.02
1962	33.81	39.17	72.97	8.18	31.16	20.52
1963	35.58	40.60	76.18	7.96	31.18	20.33
1964	37.68	43.64	81.32	7.61	30.80	20.05
1965	40.60	49.80	90.39	6.77	31.19	20.22
1966	44.01	56.87	100.88	5.14	31.31	19.89
1967	47.14	62.85	109.99	5.75	30.87	20.10
1968	45.80	66.34	112.14	5.92	30.07	20.21
1969	48.67	69.46	118.13	3.38	31.63	19.99
1970	51.02	73.12	124.14	3.92	32.99	21.04
1971	52.71	74.87	127.58	4.51	32.57	20.98
1972	53.53	75.34	128.87	6.89	36.11	23.97
1973	54.65	76.91	131.55	5.05	39.57	25.23
1974	56.42	84.52	140.93	-11.96	35.61	16.57
1975	57.84	93.73	151.57	-3.94	34.32	19.72
1976	59.26	103.38	162.64	21.92	49.50	39.45

Table A.5a

Estimated Capital Stock, Depreciation Rate, and Amount of Depreciation for the Petroleum and Coal Products Industry, 1949-1976

Year	Bldg. Cap. Stock	Equip. Cap. Stock	Total Cap. Stock	Bldg. Cap. Dep'n. Rate	Equip. Cap. Dep'n. Rate	Bldg. Cap. Dep'n.	Equip. Cap. Dep'n.
1949	6003.36	3315.21	9318.57	.0220	.0852	129.18	276.61
1950	6166.37	3247.92	9414.29	.0238	.0869	138.41	298.31
1951	6981.30	3362.89	10344.19	.0262	.0967	160.16	330.24
1952	7258.14	3366.76	10624.90	.0244	.1016	168.58	353.03
1953	7741.21	3372.81	11114.02	.0251	.1129	178.49	385.09
1954	7889.31	3287.42	11176.72	.0253	.1231	187.27	422.38
1955	8264.18	3072.99	11337.17	.0264	.1299	201.33	449.73
1956	9261.74	2965.27	12227.01	.0284	.1483	228.41	495.65
1957	10026.12	2882.26	12908.38	.0279	.1651	250.29	541.78
1958	10120.20	2499.13	12619.33	.0269	.1817	259.65	572.17
1959	10227.22	2056.53	12283.76	.0277	.2042	272.59	597.00
1960	10242.55	1583.31	11825.86	.0273	.2401	277.75	613.48
1961	10294.35	1086.66	11381.00	.0280	.2981	284.23	621.67
1962	10347.08	1030.79	11377.87	.0289	.1522	294.53	240.61
1963	10409.44	925.73	11335.17	.0293	.2181	303.54	237.56
1964	10509.57	842.34	11351.91	.0301	.2274	314.23	235.00
1965	10850.09	803.29	11653.38	.0310	.2417	327.61	225.12
1966	11390.33	860.75	12251.08	.0327	.2496	351.84	211.57
1967	12070.48	1119.28	13189.77	.0333	.2486	376.78	203.44
1968	12671.55	1582.37	14253.92	.0343	.2498	408.20	220.74
1969	13747.12	1892.27	15639.39	.0355	.2256	449.70	261.44
1970	15085.72	2215.32	17301.05	.0367	.1814	501.19	295.93
1971	16380.65	2540.89	18921.54	.0371	.1663	553.60	326.66
1972	17373.45	2767.53	20140.98	.0373	.1576	604.11	364.84
1973	18566.31	3049.50	21615.81	.0385	.1554	667.43	404.44
1974	21916.06	3867.64	25783.70	.0427	.1707	800.27	480.88
1975	24838.10	5349.11	30187.21	.0424	.1909	929.61	630.07
1976	25748.87	6491.32	32240.19	.0393	.1751	978.84	774.13

Table A.5b

Estimated Real Capital Stock, and User Cost of Capital for

the Petroleum and Coal Products Industry, 1949-1976

Year	Real Bldg. Cap. Stock	Real Equip. Cap. Stock	Total Real Cap. Stock	User Cost of Bldg. Cap.	User Cost of Equip. Cap.	User Cost of Total Cap.
1949	60.53	31.37	91.91	5.30	5.77	5.46
1950	61.16	29.83	90.99	3.08	8.78	4.95
1951	61.77	28.88	90.65	-6.32	6.69	-2.18
1952	62.96	28.50	91.45	3.63	13.47	6.70
1953	65.96	28.01	93.97	4.33	14.86	7.47
1954	68.31	26.59	94.90	7.73	15.16	9.81
1955	70.17	24.45	94.62	4.18	17.82	7.71
1956	72.54	22.09	94.63	-2.36	15.53	1.82
1957	75.35	20.22	95.57	2.96	20.16	6.60
1958	77.38	17.28	94.66	10.28	29.16	13.72
1959	77.83	13.91	91.74	8.36	32.98	12.10
1960	78.56	10.56	89.13	9.82	39.93	13.39
1961	79.47	7.26	86.72	9.51	50.66	12.95
1962	79.49	6.87	86.36	8.29	28.39	9.89
1963	79.34	6.15	85.49	8.06	38.45	10.25
1964	78.98	5.56	84.55	7.67	39.77	9.78
1965	79.69	5.27	84.96	6.86	42.29	9.06
1966	80.13	5.55	85.68	5.28	43.14	7.73
1967	81.37	7.02	88.39	5.93	43.19	8.89
1968	81.45	9.59	91.04	6.28	44.21	10.27
1969	82.04	11.12	93.16	4.19	43.65	8.90
1970	82.97	12.55	95.52	4.40	37.24	8.72
1971	83.99	13.77	97.76	5.21	33.34	9.17
1972	84.09	14.64	98.73	7.78	35.90	11.95
1973	83.20	15.85	99.05	6.11	38.62	11.31
1974	83.19	18.57	101.76	-10.64	34.24	-2.45
1975	82.97	22.46	105.42	-2.36	32.22	5.01
1976	83.36	25.78	109.14	23.58	47.54	29.24

Table A.6a

Estimated Capital Stock, Depreciation Rate, and Amount of Depreciation for the Rubber and Plastic Products Industry, 1949-1976

Year	Bldg. Cap. Stock	Equip. Cap. Stock	Total Cap. Stock	Bldg. Cap. Dep'n. Rate	Equip. Cap. Dep'n. Rate	Bldg. Cap. Dep'n.	Equip. Cap. Dep'n.
1949	148.27	515.44	663.71	.0220	.0845	3.07	40.47
1950	164.27	548.31	712.58	.0247	.0906	3.42	45.83
1951	203.14	625.49	828.63	.0282	.1024	4.25	54.40
1952	226.88	674.25	901.13	.0264	.1071	4.86	62.78
1953	247.98	724.31	972.29	.0266	.1140	5.50	72.34
1954	257.14	770.38	1027.52	.0256	.1212	5.91	83.26
1955	277.75	794.73	1072.48	.0265	.1259	6.46	93.61
1956	313.61	871.60	1185.21	.0287	.1390	7.53	108.91
1957	341.49	923.74	1265.24	.0276	.1495	8.31	126.87
1958	369.99	952.35	1322.34	.0265	.1500	8.67	138.87
1959	401.64	993.80	1395.44	.0288	.1649	9.67	154.55
1960	443.14	1080.45	1523.59	.0281	.1756	10.46	170.91
1961	466.72	1101.94	1568.65	.0291	.1887	11.61	190.16
1962	511.44	1253.47	1764.91	.0284	.1392	12.52	150.24
1963	560.21	1372.64	1932.85	.0295	.1529	13.85	168.89
1964	631.36	1516.18	2147.54	.0298	.1479	15.36	185.88
1965	718.25	1725.96	2444.21	.0308	.1470	17.50	203.08
1966	841.72	2016.81	2858.53	.0315	.1501	20.35	228.96
1967	994.18	2344.89	3339.07	.0318	.1499	23.84	263.57
1968	1189.39	2707.59	3896.98	.0322	.1476	28.25	305.75
1969	1414.59	3127.65	4542.24	.0332	.1450	34.61	352.08
1970	1675.94	3482.96	5158.89	.0325	.1464	41.61	408.64
1971	1907.14	3737.03	5644.16	.0319	.1442	48.98	468.06
1972	2208.16	4135.20	6343.36	.0309	.1401	55.61	509.82
1973	2596.01	4670.37	7266.39	.0326	.1481	65.90	567.25
1974	3312.29	5504.15	8816.43	.0357	.1606	85.06	676.00
1975	3894.95	6348.95	10243.90	.0343	.1679	105.06	848.67
1976	4143.11	6856.92	11000.03	.0302	.1483	113.79	933.51

Table A.6b

Estimated Real Capital Stock, and User Cost of Capital for the Rubber and Plastic Products Industry, 1949-1976

Year	Real Bldg. Cap. Stock	Real Equip. Cap. Stock	Total Real Cap. Stock	User Cost of Bldg. Cap.	User Cost of Equip. Cap.	User Cost of Total Cap.
1949	1.50	4.88	6.37	5.30	5.70	5.61
1950	1.63	5.04	6.66	3.18	9.18	7.71
1951	1.80	5.37	7.17	-6.10	7.36	3.98
1952	1.97	5.71	7.67	3.86	14.12	11.49
1953	2.11	6.02	8.13	4.50	15.00	12.27
1954	2.23	6.23	8.46	7.76	14.92	13.03
1955	2.36	6.32	8.68	4.19	17.31	13.75
1956	2.46	6.49	8.95	-2.32	14.29	9.73
1957	2.57	6.48	9.05	2.92	17.94	13.68
1958	2.83	6.59	9.41	10.23	24.58	20.27
1959	3.06	6.72	9.78	8.51	27.18	21.35
1960	3.40	7.21	10.61	9.93	30.25	23.74
1961	3.60	7.36	10.96	9.65	34.28	26.19
1962	3.93	8.35	12.28	8.22	26.45	20.62
1963	4.27	9.12	13.39	8.09	28.65	22.09
1964	4.74	10.01	14.76	7.63	27.74	21.27
1965	5.28	11.33	16.60	6.83	27.87	21.18
1966	5.92	13.00	18.92	5.11	27.69	20.62
1967	6.70	14.71	21.42	5.71	27.46	20.66
1968	7.64	16.41	24.05	5.94	27.36	20.55
1969	8.44	18.38	26.83	3.80	29.94	21.71
1970	9.22	19.73	28.94	3.63	31.06	22.32
1971	9.78	20.25	30.03	4.20	29.26	21.10
1972	10.69	21.88	32.56	6.45	32.59	24.01
1973	11.63	24.27	35.90	4.81	37.23	26.72
1974	12.57	26.42	39.00	-12.48	32.13	17.75
1975	13.01	26.66	39.67	-4.79	26.74	16.40
1976	13.41	27.23	40.65	20.78	40.81	34.20

Table A.7a

Estimated Capital Stock, Depreciation Rate, and Amount of Depreciation for the Stone, Clay and Glass Products Industry, 1949-1976

Year	Bldg. Cap. Stock	Equip. Cap. Stock	Total Cap. Stock	Bldg. Cap. Dep'n. Rate	Equip. Cap. Dep'n. Rate	Bldg. Cap. Dep'n.	Equip. Cap. Dep'n.
1949	467.70	1163.96	1631.66	.0220	.0648	9.45	66.90
1950	519.36	1289.63	1808.99	.0253	.0712	10.77	77.75
1951	669.47	1527.75	2197.23	.0282	.0785	13.43	94.16
1952	735.68	1640.24	2375.91	.0275	.0802	15.98	110.63
1953	811.48	1747.71	2559.19	.0261	.0808	17.82	125.30
1954	869.33	1876.03	2745.36	.0258	.0845	19.30	141.31
1955	1009.72	2113.00	3122.72	.0272	.0878	21.71	157.59
1956	1327.72	2565.97	3893.68	.0305	.1007	27.03	192.01
1957	1576.39	2994.40	4570.80	.0312	.1049	34.19	236.59
1958	1635.91	3084.57	4720.48	.0279	.0996	38.55	271.51
1959	1739.27	3276.12	5015.39	.0268	.0979	41.53	297.47
1960	1814.40	3402.28	5216.68	.0269	.1040	44.22	327.79
1961	1853.02	3413.66	5266.68	.0272	.1061	46.87	352.35
1962	1943.63	3464.40	5408.02	.0273	.1106	49.26	375.86
1963	2062.89	3521.78	5584.68	.0282	.1176	52.58	402.49
1964	2162.46	3611.12	5773.58	.0290	.1246	56.85	432.85
1965	2320.29	3733.92	6054.22	.0292	.1316	61.06	466.40
1966	2561.13	4124.28	6685.41	.0306	.1134	67.66	412.20
1967	2790.41	4406.10	7196.52	.0311	.1200	75.39	456.49
1968	2998.57	4644.22	7642.79	.0313	.1174	83.56	496.98
1969	3335.33	4969.10	8304.43	.0320	.1155	93.72	527.16
1970	3718.60	5296.87	9015.47	.0330	.1198	106.49	573.75
1971	4076.50	5629.90	9706.40	.0329	.1215	119.15	626.37
1972	4409.45	6075.48	10484.93	.0329	.1204	131.07	666.16
1973	4876.92	6609.80	11486.72	.0340	.1222	146.89	704.83
1974	5872.93	7656.51	13529.44	.0379	.1278	180.26	790.19
1975	6705.38	9150.00	15855.38	.0369	.1317	212.32	942.18
1976	6972.01	9849.67	16821.68	.0337	.1198	224.64	1048.77

Table A.7b

Estimated Real Capital Stock, and User Cost of Capital for the Stone, Clay and Glass Products Industry, 1949-1976

Year	Real Bldg. Cap. Stock	Real Equip. Cap. Stock	Total Real Cap. Stock	User Cost of Bldg. Cap.	User Cost of Equip. Cap.	User Cost of Total Cap.
1949	4.72	11.01	15.73	5.30	3.61	4.12
1950	5.15	11.84	17.00	3.24	7.07	5.91
1951	5.92	13.12	19.04	-6.09	4.57	1.26
1952	6.38	13.88	20.26	3.98	10.94	8.75
1953	6.91	14.51	21.43	4.45	11.01	8.89
1954	7.53	15.17	22.70	7.78	10.39	9.52
1955	8.57	16.81	25.38	4.27	12.53	9.74
1956	10.40	19.12	29.52	-2.09	9.14	5.18
1957	11.85	21.01	32.86	3.40	11.58	8.63
1958	12.51	21.33	33.84	10.40	17.29	14.74
1959	13.24	22.16	35.40	8.25	17.28	13.90
1960	13.92	22.70	36.61	9.77	19.52	15.81
1961	14.30	22.80	37.10	9.40	21.91	17.08
1962	14.93	23.08	38.01	8.08	22.15	16.62
1963	15.72	23.40	39.13	7.92	23.34	17.14
1964	16.25	23.85	40.10	7.52	24.21	17.45
1965	17.04	24.51	41.55	6.61	25.52	17.76
1966	18.02	26.57	44.59	4.98	22.00	15.12
1967	18.81	27.65	46.46	5.61	22.70	15.78
1968	19.27	28.14	47.42	5.80	22.36	15.63
1969	19.91	29.21	49.11	3.60	24.93	16.29
1970	20.45	30.00	50.45	3.72	26.37	17.19
1971	20.90	30.51	51.42	4.39	25.06	16.66
1972	21.34	32.14	53.48	6.85	28.86	20.08
1973	21.86	34.35	56.20	5.12	32.24	21.69
1974	22.29	36.75	59.05	-11.90	25.30	11.25
1975	22.40	38.42	60.81	-4.01	18.12	9.97
1976	22.57	39.12	61.69	21.83	33.63	29.31

Table A.8a

Estimated Capital Stock, Depreciation Rate, and Amount of Depreciation for the Primary Metal Products Industry, 1949-1976

Year	Bldg. Cap. Stock	Equip. Cap. Stock	Total Cap. Stock	Bldg. Cap. Dep'n. Rate	Equip. Cap. Dep'n. Rate	Bldg. Cap. Dep'n.	Equip. Cap. Dep'n.
1949	1999.15	4524.59	6523.74	.0220	.0660	41.75	274.47
1950	2125.10	4762.70	6887.80	.0245	.0704	46.06	309.06
1951	2805.86	5592.36	8398.22	.0271	.0768	55.08	357.90
1952	3335.89	6335.18	9671.06	.0281	.0820	67.04	417.46
1953	3713.98	6775.54	10489.52	.0281	.0871	80.46	494.19
1954	3873.25	7070.79	10944.05	.0259	.0867	87.89	559.53
1955	4150.90	7269.98	11420.87	.0264	.0879	96.55	611.78
1956	4905.62	8232.54	13138.16	.0283	.0973	111.85	699.35
1957	5758.49	9405.40	15163.89	.0286	.1057	128.52	820.35
1958	6044.88	9516.23	15561.11	.0280	.1060	143.23	926.36
1959	6271.40	9445.73	15717.13	.0275	.1053	155.69	1004.45
1960	6590.62	9598.83	16189.45	.0267	.1094	162.25	1064.36
1961	6715.88	9299.06	16014.94	.0278	.1180	172.93	1130.73
1962	6837.68	9028.08	15865.76	.0277	.1238	181.35	1186.40
1963	7090.08	8864.85	15954.94	.0280	.1336	188.85	1245.28
1964	7414.81	9062.41	16477.22	.0291	.1458	200.24	1319.73
1965	7922.37	9819.29	17741.65	.0298	.1148	214.54	1024.13
1966	8629.65	11056.16	19685.81	.0312	.1223	236.72	1115.56
1967	9434.99	12549.51	21984.49	.0315	.1247	260.83	1247.24
1968	10275.97	14053.77	24329.74	.0322	.1210	289.61	1373.93
1969	11361.26	15206.59	26567.86	.0331	.1136	327.96	1476.03
1970	12559.93	16315.23	28875.17	.0335	.1104	370.83	1599.61
1971	13541.22	17018.40	30559.61	.0334	.1108	412.16	1748.04
1972	14314.79	17343.42	31658.21	.0332	.1077	447.90	1835.98
1973	15389.13	17691.91	33081.03	.0344	.1075	493.76	1875.04
1974	18333.48	20120.14	38453.63	.0384	.1146	593.99	2023.61
1975	20878.31	23997.41	44875.72	.0382	.1271	694.22	2434.91
1976	21470.46	26161.04	47631.50	.0352	.1184	733.14	2723.59

Table A.8b

Estimated Real Capital Stock, and User Cost of Capital for the Primary Metals Products Industry, 1949-1976

Year	Real Bldg. Cap. Stock	Real Equip. Cap. Stock	Total Real Cap. Stock	User Cost of Bldg. Cap.	User Cost of Equip. Cap.	User Cost of Total Cap.
1949	20.16	42.82	62.98	5.30	3.75	4.25
1950	21.08	43.74	64.82	3.16	6.98	5.73
1951	24.83	48.03	72.85	-6.22	4.37	.76
1952	28.93	53.62	82.56	4.06	11.15	8.66
1953	31.65	56.27	87.92	4.68	11.76	9.21
1954	33.54	57.19	90.73	7.79	10.65	9.60
1955	35.25	57.83	93.08	4.18	12.55	9.38
1956	38.42	61.34	99.76	-2.37	8.68	4.43
1957	43.28	65.99	109.27	3.04	11.69	8.27
1958	46.22	65.81	112.03	10.42	18.20	14.99
1959	47.73	63.90	111.62	8.34	18.36	14.08
1960	50.55	64.03	114.59	9.74	20.33	15.66
1961	51.84	62.11	113.95	9.48	23.70	17.23
1962	52.53	60.15	112.68	8.13	24.13	16.67
1963	54.04	58.91	112.95	7.89	25.74	17.20
1964	55.73	59.85	115.58	7.53	27.42	17.83
1965	58.19	64.45	122.63	6.70	22.96	15.24
1966	60.71	71.24	131.95	5.07	23.38	14.96
1967	63.60	78.75	142.35	5.68	23.44	15.50
1968	66.05	85.16	151.21	5.94	22.97	15.53
1969	67.80	89.38	157.18	3.79	24.60	15.62
1970	69.08	92.41	161.49	3.82	24.70	15.77
1971	69.43	92.24	161.67	4.49	23.09	15.10
1972	69.28	91.75	161.03	6.93	26.46	18.06
1973	68.97	91.94	160.90	5.21	29.41	19.04
1974	69.60	96.58	166.18	-11.75	22.56	8.19
1975	69.74	100.75	170.49	-3.61	17.04	8.59
1976	69.51	103.90	173.41	22.31	33.27	28.88

Table A.9a

Estimated Capital Stock, Depreciation Rate, and Amount of Depreciation for the Fabricated Metal Products, 1949-1976

Year	Bldg. Cap. Stock	Equip. Cap. Stock	Total Cap. Stock	Bldg. Cap. Dep'n. Rate	Equip. Cap. Dep'n. Rate	Bldg. Cap. Dep'n.	Equip. Cap. Dep'n.
1949	553.47	1337.16	1890.63	.0220	.0881	11.13	106.40
1950	643.04	1477.71	2120.75	.0254	.0972	12.74	124.05
1951	816.36	1675.44	2491.79	.0295	.1108	16.60	152.64
1952	906.99	1768.25	2675.24	.0270	.1113	19.47	175.84
1953	1050.57	1899.18	2949.75	.0263	.1176	21.94	199.97
1954	1123.08	2049.12	3172.20	.0269	.1280	24.85	230.73
1955	1277.24	2169.00	3446.24	.0270	.1347	27.92	262.60
1956	1530.68	2376.41	3907.09	.0298	.1494	34.13	311.35
1957	1695.36	2574.09	4269.45	.0287	.1570	39.73	363.60
1958	1769.29	2521.71	4291.00	.0264	.1601	42.10	403.93
1959	1872.58	2502.44	4375.02	.0273	.1684	45.54	439.68
1960	1944.10	2409.95	4354.04	.0272	.1849	48.27	476.68
1961	1980.83	2369.53	4350.36	.0274	.1397	50.93	354.40
1962	2076.90	2403.58	4480.48	.0276	.1504	53.41	361.92
1963	2174.16	2472.34	4646.50	.0286	.1556	56.96	369.63
1964	2321.50	2655.91	4977.41	.0291	.1583	60.87	381.37
1965	2508.17	2874.50	5382.67	.0301	.1622	66.32	403.59
1966	2771.65	3222.94	5994.59	.0311	.1611	73.85	430.63
1967	3094.37	3674.68	6769.05	.0314	.1601	82.33	468.83
1968	3393.95	4085.49	7479.44	.0321	.1570	92.96	519.46
1969	3884.29	4598.80	8483.09	.0326	.1485	105.90	564.94
1970	4359.49	5018.63	9378.11	.0336	.1486	122.97	625.90
1971	4772.15	5356.28	10128.43	.0328	.1460	138.29	696.63
1972	5195.74	5774.70	10970.44	.0325	.1419	151.99	744.00
1973	5829.74	6416.49	12246.23	.0339	.1471	171.16	807.53
1974	7180.98	7457.50	14638.48	.0378	.1631	212.28	958.85
1975	8352.22	8970.72	17322.94	.0369	.1706	254.14	1184.92
1976	8843.36	9872.21	18715.56	.0334	.1567	272.41	1335.90

Table A.9b

Estimated Real Capital Stock, and User Cost of Capital for the Fabricated Metal Products Industry, 1949-1976

Year	Real Bldg. Cap. Stock	Real Equip. Cap. Stock	Total Real Cap. Stock	User Cost of Bldg. Cap.	User Cost of Equip. Cap.	User Cost of Total Cap.
1949	5.58	12.65	18.23	5.30	6.08	5.84
1950	6.38	13.57	19.95	3.25	9.90	7.77
1951	7.22	14.39	21.61	-5.95	8.33	3.56
1952	7.87	14.97	22.83	3.93	14.61	10.93
1953	8.95	15.77	24.72	4.48	15.44	11.47
1954	9.72	16.57	26.30	7.91	15.77	12.86
1955	10.85	17.25	28.10	4.25	18.42	12.95
1956	11.99	17.71	29.69	-2.18	15.68	8.47
1957	12.74	18.06	30.80	3.06	19.01	12.41
1958	13.53	17.44	30.97	10.21	26.03	19.12
1959	14.25	16.93	31.18	8.32	27.69	18.84
1960	14.91	16.08	30.99	9.80	31.65	21.14
1961	15.29	15.83	31.12	9.43	26.94	18.33
1962	15.96	16.01	31.97	8.12	28.12	18.14
1963	16.57	16.43	33.00	7.97	29.05	18.47
1964	17.45	17.54	34.99	7.53	29.30	18.45
1965	18.42	18.87	37.29	6.73	30.19	18.60
1966	19.50	20.77	40.26	5.05	29.41	17.61
1967	20.86	23.06	43.92	5.66	29.09	17.96
1968	21.82	24.76	46.57	5.94	28.90	18.14
1969	23.18	27.03	50.21	3.71	30.53	18.15
1970	23.98	28.42	52.40	3.84	31.45	18.82
1971	24.47	29.03	53.50	4.37	29.58	18.05
1972	25.15	30.55	55.70	6.78	32.92	21.12
1973	26.13	33.34	59.47	5.08	37.04	23.00
1974	27.26	35.80	63.06	-11.91	32.66	13.39
1975	27.90	37.66	65.56	-4.00	27.39	14.03
1976	28.63	39.21	67.84	21.75	42.91	33.98

Table A.10a

Estimated Capital Stock, Depreciation Rate, and Amount of Depreciation for the Machinery Industry, 1949-1976

Year	Bldg. Cap. Stock	Equip. Cap. Stock	Total Cap. Stock	Bldg. Cap. Dep'n. Rate	Equip. Cap. Dep'n. Rate	Bldg. Cap. Dep'n.	Equip. Cap. Dep'n.
1949	1008.90	2271.91	3280.82	.0220	.0880	20.51	184.17
1950	1089.36	2380.54	3469.90	.0251	.0953	23.23	210.81
1951	1421.55	2721.42	4142.97	.0275	.1058	28.20	247.76
1952	1648.11	2920.49	4568.61	.0278	.1128	33.95	287.15
1953	1870.12	3168.47	5038.60	.0274	.1197	39.80	330.57
1954	1996.25	3402.94	5399.19	.0264	.1290	44.24	384.08
1955	2117.88	3562.43	5680.30	.0270	.1340	49.64	435.77
1956	2463.24	3958.37	6421.61	.0280	.1483	57.00	513.10
1957	2851.29	4288.70	7139.99	.0281	.1588	64.58	604.00
1958	2929.49	4158.22	7087.71	.0277	.1596	71.09	671.04
1959	3032.74	3965.67	6998.41	.0271	.1670	75.85	726.65
1960	3120.73	3757.15	6877.87	.0268	.1821	78.89	774.18
1961	3182.33	3684.75	6867.08	.0275	.1379	82.60	554.69
1962	3290.92	3662.27	6953.19	.0279	.1513	86.65	567.75
1963	3396.64	3698.48	7095.11	.0286	.1584	91.36	585.13
1964	3614.39	3840.75	7455.15	.0291	.1619	96.51	594.26
1965	3863.11	4209.42	8072.54	.0304	.1638	104.80	609.79
1966	4418.55	4798.93	9217.48	.0313	.1672	115.66	646.04
1967	4985.40	5584.04	10569.44	.0328	.1644	132.31	704.99
1968	5520.76	6294.26	11815.02	.0326	.1601	150.55	788.70
1969	6189.88	7084.42	13274.30	.0330	.1477	172.74	854.21
1970	6996.64	7788.63	14785.27	.0332	.1450	197.47	940.71
1971	7685.58	8379.49	16065.07	.0332	.1431	223.20	1052.10
1972	8323.77	8922.50	17246.27	.0328	.1402	245.93	1141.25
1973	9243.60	9641.66	18885.26	.0339	.1436	275.87	1232.62
1974	11428.46	11454.64	22883.10	.0378	.1585	339.56	1439.40
1975	13363.60	13859.66	27223.26	.0373	.1733	407.49	1808.92
1976	14166.78	15209.30	29376.08	.0338	.1568	438.36	2053.41

Table A.10b

Estimated Real Capital Stock, and User Cost of Capital for the Machinery Industry, 1949-1976

Year	Real Bldg. Cap. Stock	Real Equip. Cap. Stock	Total Real Cap. Stock	User Cost of Bldg. Cap.	User Cost of Equip. Cap.	User Cost of Total Cap.
1949	10.17	21.50	31.67	5.30	6.07	5.82
1950	10.80	21.86	32.67	3.22	9.69	7.55
1951	12.58	23.37	35.95	-6.18	7.76	2.88
1952	14.30	24.72	39.01	4.02	14.79	10.85
1953	15.94	26.31	42.25	4.61	15.69	11.51
1954	17.28	27.53	44.81	7.85	15.89	12.79
1955	17.98	28.34	46.32	4.25	18.33	12.86
1956	19.29	29.49	48.78	-2.41	15.53	8.44
1957	21.43	30.09	51.52	2.99	19.26	12.49
1958	22.40	28.75	51.15	10.38	25.97	19.14
1959	23.08	26.83	49.91	8.28	27.49	18.61
1960	23.94	25.06	49.00	9.76	31.23	20.74
1961	24.57	24.61	49.18	9.44	26.68	18.06
1962	25.28	24.40	49.68	8.16	28.26	18.03
1963	25.89	24.58	50.47	7.96	29.48	18.44
1964	27.16	25.37	52.53	7.53	29.85	18.31
1965	28.37	27.63	56.00	6.78	30.43	18.45
1966	31.08	30.92	62.01	5.08	30.34	17.68
1967	33.61	35.04	68.65	5.86	29.77	18.07
1968	35.49	38.14	73.63	6.02	29.41	18.13
1969	36.94	41.64	78.58	3.77	30.41	17.89
1970	38.48	44.11	82.60	3.76	30.80	18.21
1971	39.40	45.42	84.82	4.45	29.05	17.63
1972	40.29	47.20	87.49	6.83	32.61	20.74
1973	41.43	50.10	91.53	5.09	36.35	22.20
1974	43.38	54.99	98.37	-11.93	31.69	12.46
1975	44.64	58.19	102.83	-3.87	28.04	14.18
1976	45.86	60.40	106.27	21.86	42.94	33.84

Table A.11a

Estimated Capital Stock, Depreciation Rate, and Amount of Depreciation for the Electrical and Electronic Equipment Industry, 1949-1976

Year	Bldg. Cap. Stock	Equip. Cap. Stock	Total Cap. Stock	Bldg. Cap. Dep'n. Rate	Equip. Cap. Dep'n. Rate	Bldg. Cap. Dep'n.	Equip. Cap. Dep'n.
1949	443.94	1047.13	1491.06	.0220	.1057	8.86	101.51
1950	491.17	1106.03	1597.19	.0256	.1166	10.22	118.36
1951	657.18	1241.69	1898.87	.0281	.1317	12.70	142.13
1952	780.32	1316.35	2096.67	.0284	.1392	15.66	164.60
1953	907.31	1425.97	2333.29	.0280	.1510	18.78	190.29
1954	964.58	1488.45	2453.04	.0269	.1666	21.36	223.57
1955	1052.67	1525.95	2578.63	.0267	.1725	23.88	252.55
1956	1260.19	1679.28	2939.47	.0286	.1968	28.13	297.93
1957	1476.49	1783.00	3259.50	.0287	.2169	32.72	353.35
1958	1556.83	1721.69	3278.53	.0277	.2211	36.44	394.32
1959	1697.64	1848.10	3545.74	.0274	.1617	39.78	292.45
1960	1840.18	1995.51	3835.69	.0277	.1797	43.28	316.22
1961	1971.11	2076.47	4047.58	.0281	.1812	47.40	339.54
1962	2088.68	2200.80	4289.48	.0284	.1791	51.86	356.90
1963	2225.43	2354.91	4580.34	.0282	.1813	55.85	377.35
1964	2389.40	2539.84	4929.24	.0288	.1804	60.61	398.11
1965	2604.53	2938.74	5543.27	.0294	.1803	66.41	427.21
1966	3013.27	3528.04	6541.31	.0305	.1898	74.56	484.98
1967	3507.60	4149.13	7656.73	.0318	.1875	86.36	561.35
1968	3993.85	4704.97	8698.82	.0321	.1803	101.03	653.11
1969	4584.23	5343.08	9927.31	.0323	.1738	118.76	746.61
1970	5220.81	5821.57	11042.38	.0322	.1769	138.54	857.96
1971	5760.21	6203.23	11963.44	.0317	.1734	157.78	961.24
1972	6222.70	6435.74	12658.44	.0312	.1713	174.61	1042.24
1973	6953.16	7005.25	13958.42	.0321	.1753	195.66	1114.20
1974	8492.80	8180.13	16672.93	.0360	.1989	242.22	1303.06
1975	9720.85	9254.34	18975.20	.0352	.2133	288.55	1617.73
1976	10147.85	9862.78	20010.63	.0317	.1857	305.90	1736.86

Table A.11b

Estimated Real Capital Stock, and User Cost of Capital for the Electrical and Electronic Equipment Industry, 1949-1976

Year	Real Bldg. Cap. Stock	Real Equip. Cap. Stock	Total Real Cap. Stock	User Cost of Bldg. Cap.	User Cost of Equip. Cap.	User Cost of Total Cap.
1949	4.48	9.91	14.39	5.30	7.94	7.12
1950	4.87	10.16	15.03	3.27	12.01	9.17
1951	5.81	10.66	16.48	-6.11	10.77	4.82
1952	6.77	11.14	17.91	4.10	17.91	12.69
1953	7.73	11.84	19.57	4.67	19.46	13.62
1954	8.35	12.04	20.39	7.91	20.54	15.37
1955	8.94	12.14	21.08	4.22	23.18	15.14
1956	9.87	12.51	22.38	-2.33	22.05	11.30
1957	11.10	12.51	23.61	3.06	27.54	16.03
1958	11.90	11.91	23.81	10.39	34.86	22.62
1959	12.92	12.50	25.42	8.33	26.70	17.36
1960	14.11	13.31	27.43	9.87	30.87	20.06
1961	15.22	13.87	29.08	9.52	33.15	20.79
1962	16.05	14.66	30.71	8.21	32.43	19.78
1963	16.96	15.65	32.61	7.91	32.92	19.91
1964	17.96	16.77	34.73	7.49	32.66	19.65
1965	19.13	19.29	38.42	6.64	32.94	19.84
1966	21.20	22.73	43.93	4.97	33.85	19.91
1967	23.64	26.04	49.68	5.71	33.45	20.25
1968	25.67	28.51	54.18	5.94	32.75	20.04
1969	27.36	31.41	58.76	3.65	34.84	20.32
1970	28.71	32.97	61.69	3.58	36.44	21.14
1971	29.53	33.62	63.16	4.16	34.63	20.38
1972	30.12	34.05	64.16	6.50	38.49	23.48
1973	31.16	36.40	67.56	4.68	42.46	25.04
1974	32.24	39.27	71.51	-12.38	40.12	16.45
1975	32.47	38.85	71.32	-4.53	37.57	18.40
1976	32.85	39.17	72.02	21.23	50.22	37.00

Table A.12a

Estimated Capital Stock, Depreciation Rate, and Amount of Depreciation for the Transportation Equipment Industry, 1949-1976

Year	Bldg. Cap. Stock	Equip. Cap. Stock	Total Cap. Stock	Bldg. Cap. Dep'n. Rate	Equip. Cap. Dep'n. Rate	Bldg. Cap. Dep'n.	Equip. Cap. Dep'n.
1949	893.27	2423.18	3316.45	.0220	.0887	19.02	202.85
1950	964.31	2536.54	3500.85	.0240	.0939	20.59	227.03
1951	1309.67	2855.96	4165.63	.0275	.1068	24.99	266.72
1952	1624.43	2984.98	4609.42	.0289	.1126	31.24	305.52
1953	1787.81	3233.64	5021.45	.0292	.1191	39.02	344.97
1954	1898.30	3663.55	5561.84	.0255	.1316	42.19	400.38
1955	2104.52	3891.60	5996.12	.0268	.1417	47.12	470.58
1956	2625.47	4693.44	7318.91	.0291	.1502	56.28	559.49
1957	2990.03	5117.32	8107.35	.0298	.1665	67.91	691.99
1958	3031.18	4861.65	7892.83	.0270	.1549	73.77	772.31
1959	3164.71	4668.43	7833.14	.0265	.1594	77.82	827.38
1960	3257.39	4382.09	7639.48	.0268	.1778	81.55	883.78
1961	3341.30	4245.77	7587.07	.0272	.1352	85.43	639.83
1962	3528.22	4190.02	7718.24	.0278	.1507	90.07	659.44
1963	3732.73	4269.38	8002.11	.0288	.1598	96.63	680.05
1964	3966.02	4569.78	8535.80	.0293	.1673	104.15	702.83
1965	4453.32	5013.65	9466.97	.0299	.1739	113.04	747.14
1966	5115.68	5705.13	10820.81	.0320	.1745	129.79	802.39
1967	5734.57	6271.23	12005.80	.0321	.1692	149.26	864.09
1968	6259.78	6742.83	13002.61	.0317	.1597	169.22	935.66
1969	7115.18	7378.33	14493.51	.0320	.1463	192.18	950.25
1970	7930.19	7816.55	15746.73	.0329	.1468	222.15	1020.31
1971	8573.84	7988.44	16562.28	.0322	.1466	248.59	1122.32
1972	9154.59	9327.67	18482.26	.0318	.1438	270.75	1174.51
1973	10051.13	10223.34	20274.47	.0331	.1633	300.63	1336.29
1974	12019.45	12147.61	24167.07	.0371	.1658	367.10	1574.61
1975	13661.51	14243.17	27904.68	.0363	.1786	430.33	1976.14
1976	14060.31	15578.06	29638.37	.0332	.1577	453.89	2190.57

Table A.12b

Estimated Real Capital Stock, and User Cost of Capital for the Transportation Equipment Industry, 1949-1976

Year	Real Bldg. Cap. Stock	Real Equip. Cap. Stock	Total Real Cap. Stock	User Cost of Bldg. Cap.	User Cost of Equip. Cap.	User Cost of Total Cap.
1949	9.01	22.93	31.94	5.30	6.14	5.90
1950	9.56	23.30	32.86	3.11	9.54	7.67
1951	11.59	24.53	36.11	-6.18	7.87	3.36
1952	14.09	25.26	39.36	4.15	14.77	10.97
1953	15.23	26.85	42.09	4.81	15.61	11.70
1954	16.44	29.63	46.07	7.75	16.21	13.19
1955	17.87	30.96	48.83	4.23	19.31	13.79
1956	20.56	34.97	55.53	-2.27	15.79	9.10
1957	22.47	35.90	58.37	3.20	20.37	13.76
1958	23.18	33.62	56.80	10.29	25.29	19.17
1959	24.08	31.58	55.66	8.21	26.36	18.51
1960	24.99	29.23	54.22	9.75	30.59	20.99
1961	25.79	28.36	54.15	9.40	26.26	18.23
1962	27.11	27.92	55.02	8.14	28.17	18.30
1963	28.45	28.37	56.82	7.99	29.68	18.82
1964	29.81	30.18	59.99	7.56	30.67	19.19
1965	32.71	32.91	65.61	6.70	31.97	19.37
1966	35.99	36.76	72.75	5.18	31.48	18.47
1967	38.66	39.35	78.01	5.76	30.53	18.26
1968	40.24	40.86	81.09	5.87	29.35	17.70
1969	42.46	43.37	85.83	3.59	30.17	17.02
1970	43.62	44.27	87.89	3.72	31.12	17.52
1971	43.96	43.30	87.26	4.25	29.69	16.88
1972	44.31	49.34	93.65	6.64	33.29	20.68
1973	45.04	53.13	98.17	4.91	40.14	23.98
1974	45.63	58.31	103.94	-12.10	33.23	13.33
1975	45.63	59.80	105.43	-4.20	29.29	14.80
1976	45.52	61.87	107.39	21.70	43.17	34.07

BIBLIOGRAPHY

Abramovitz, M. (1956) *"Resources and Output Trends in the U.S. Since 1870"*, American Economic Review, Papers and Proceedings, XL, No. 2.

Ahmad, S. (1966) *"On the Theory of Induced Invention"*, Economic Journal, June.

Ahmad, S. (1967) *"Reply to Professor Fellner"*, Economic Journal, September.

Ames, E. (1961) *"Research, Invention, Development, and Innovation"*, American Economic Review, June.

Archer, L.B. (1970) *"Technological Innovation and Added-value", In:* M. Goldsmith (ed.) *"Technological Innovation and the Economy"*, Wiley-Interscience.

Arrow, J.K. (1962) *"Economic Welfare and the Allocation of Resources for Invention". In: "The Rate and Direction of Inventive Activity: Economic and Social Factors"*, Princeton University Press.

Arrow, J.K. (1969) *"Classificatory Notes on the Production and Transmission of Technological Knowledge", American Economic Review, May.*

Aujac, H. (1970) *"R and D Policy and Economic Growth". In:* M. Goldsmith (ed.) *"Technological Innovation and the Economy"*, Wiley-Interscience.

Bailey, M. (1972) *"Research and Development Cost and Returns: The U.S. Pharmaceutical Industry"*, Journal of Political Economy, January/February.

Binswanger, H.P. (1974) *"A Microeconomic Approach to Induced Innovation"*, Economic Journal, December.

Binswanger, H.P., Ruttan, V.W. (eds.)(1978) *"Induced Innovation: Technology, Institutions, and Development"*, Baltimore: Johns Hopkins University Press.

Blaug, M. (1963) *"A Survey of the Theory of Process-Innovations"*, Economica, February.

Bloom, G.F. (1946) *"A Note on Hicks' Theory of Inventions"*, American Economic Review, March.

Bloom, G.F. (1951) *"Wage Pressures and Technological Discovery"*, American Economic Review, September.

Board of Governors of the Federal Reserve System (1976) *"Annual Statistical Digest"*, Washington, D.C., U.S. Government Printing Office.

Board of Governors of the Federal Reserve System (1976) *"Banking and Monetary Statistics, 1941-1970"*, Washington, D.C., U.S. Government Printing Office.

Boylan, M.G. (1977) *"The Sources of Technological Innovations", In:* B. Gold (ed.) *"Research, Technological Change, and Economic Analysis"*, Lexington.

Boylan, M.G. (1977) *"Reported Economic Effects of Technological Changes". In:* B. Gold (ed.) *"Research, Technological Change, and Economic Analysis"*, Lexington.

Brozen, Y. (1951) *"Invention, Innovation and Imitation"*, American Economic Review, Vol. 41.

Brozen, Y. (1957) *"Determinants of the Direction of Technical Change"*, American Economic Review, May.

Brozen, Y. (1960) *"Trends in Industrial Research and Development"*, Journal of Business, July.

Brozen, Y. (1965) *"R&D Differences Among Industries", In:* R. Tybout (ed.) *"Economics of Research and Development"*, Ohio University Press.

Bruton, H.J. (1956) *Innovations and Equilibrium Growth"*, Economic Journal, September.

Burn, D. (1970) *"The Investment Decision". In:* M. Goldsmith (ed.) *"Technological Innovation and the Economy"*, Wiley-Interscience.

Capron, W. (1971) *"Technological Change in Regulated Industries"*, Brookings Institution.

Carter, C.F., and Williams, R.B. (1957) *"Industry and Technical Progress"*, Oxford University Press.

Carter, C.F., and Williams, R.B. (1958) *"Investment in Innovation"*, Oxford University Press.

Charpie, R.A. (1970) *"Technological Innovation and the International Economy". In:* M. Goldsmith (ed.) *"Technological Innovation and the Economy"*, Wiley-Interscience.

Comanor, W. (1965) *"Research and Technical Change in the Pharmaceutical Industry"*, Review of Economics and Statistics, May.

Comanor, W. (1967) *"Market Structure, Product Differentiation, and Industrial Research"*, Quarterly Journal of Economics, November.

Comanor, W. and Scherer, F. (1969) *"Patent Statistics as a Measure of Technical Change"*, Journal of Political Economy, May/June.

Commerce Clearing House (1976) *"1977 U.S. Master Tax Guide"*, Chicago.

Conlisk, J. (1971) *"Nonconstant Returns to Scale and the Technical Change Frontier"*, Quarterly Journal of Economics, August.

Creamer, D. (1954) *"Capital and Output Trends in Manufacturing Industries, 1880-1948"*, National Bureau of Economic Research.

Creamer, D. (1961) *"Capital Expansion and Capacity in Postwar Manufacturing"*, National Industrial Conference Board, New York.

Creamer, D., Dobrovolsky, S., and Borenstein, I. (1960) *"Capital in Manufacturing and Mining"*, National Bureau of Economic Research, Princeton University Press.

Denison, E. (1962) *"United States Economic Growth"*, Journal of Business, April.

Diewert, W.E. (1971) *"An Application of the Shephard Duality Theorem: A Generalized Leontief Production Function"*, Journal of Political Economy, May-June.

Diewart, D.W. (1978) *"Duality Approach to Microeconomic Theory"*, Department of Economics, University of British Columbia, Discussion paper 78-09.

Drandakis, E.M. and Phelps, E.S. (1966) *"A Model of Induced Invention, Growth and Distribution"*, Economic Journal, December.

Duckworth, J.C. (1970) *"The Role of Government". In:* M. Goldsmith (ed.) *"Technological Innovation and the Economy"*, Wiley-Interscience.

Elliot, J. (1971) *"Funds Flow vs. Expectational Theories of Research and Development Expenditures in the Firm"*, Southern Economic Journal, April.

Enos, J. (1958) *"A Measure of the Rate of Technological Progress in the Petroleum Refining Industry"*, Journal of Industrial Economics, June.

Evenson , R.E., and Kislev, Y. (1975) *"Agricultural Research and Productivity"*, Economic Growth Center, Yale University Press.

Fellner, W. (1951) *"The Influence of Market Structure on Technological Progress"*, Quarterly Journal of Economics, November.

Fellner, W. (1956) *"Trends and Cycles in Economic Activity"*, Holt, Rinehart & Winston.

Fellner, W. (1961a) *"Appraisal of the Labour-saving and Capital-saving Character of Innovations". In:* F. Lutz and D.C. Hague (eds.) *"The Theory of Capital"*, International Economic Association.

Fellner, W. (1961b) *"Two Propositions in the Theory of Induced Innovations"*, Economic Journal, June.

Fellner, W. (1962) *"Does the Market Direct the Relative Factor-saving Effects of Technological Progress?". In:* R. Nelson (ed.) *"The Rate and Direction of Inventive Activity: Economic and Social Factors"*, Princeton University Press.

Fellner, W. (1967) *"Measures of Technological Progress in the Light of Recent Growing Theories"*, American Economic Review, December.

Fellner, W. (1971) *"Empirical Support for the Theory of Induced Innovations"*, Quarterly Journal of Economics, November.

Fisher, F., and Temin, P. (1973)*"Returns to Scale in R&D: What does the Schumpeterian Hypothesis Imply?"*, Journal of Political Economy, January/February.

Freeman, C. (1970) *"Innovation and Coupling Systems in Research and Development". In:* M. Goldsmith (ed.) *"Technological Innovation and the Economy"*, Wiley-Interscience.

Freeman, C. (1973) *"A Study of Success and Failure in Industrial Innovation". In:* B.R. Williams (ed.) *"Science and Technology in Economic Growth"*, International Economic Association.

Freeman, C. (1974) *"The Economics of Industrial Innovation"*, Penguin.

Galbraith, J.K. (1973) *"Technology in the Developed Economy". In:* B.R. Williams (ed.) *"Science and Technology in Economic Growth"*, International Economic Association.

Gellman, A.J. (1970) *"Market Analysis and Marketing". In:* M. Goldsmith (ed.) *"Technological Innovation and the Economy"*, Wiley-Interscience.

Gellman, A. (1971) *"Surface Freight Transportation". In:* W. Capron (ed.) *"Technological Change in Regulated Industries"*, Brookings Institution.

Gilfillan, S.C. (1935) *"The Sociology of Invention"*, Follett Publishing.

Gilfillan, S.C. (1952) *"Prediction of Technical Change"*, Review of Economics and Statistics, VOl. 34.

Gold, B. (ed.) (1977) *"Research, Technological Change, and Economic Analysis*, Lexington Books (D.C. Heath & Company).

Goldsmith, M. (ed.) (1970) *"Technological Innovation and the Economy"*, Wiley-Interscience.

Grabowski, H. (1968) *"The Determinants of Industrial Research and Development: A Study of the Chemical, Drug, and Petroleum Industries"*, Journal of Political Economy, March/April.

Grabowski, H., Vernon, J., and Lacy, T. (1976) *"The Effects of Regulatory Policy on Incentives to Innovate: An International Comparative Analysis". In:* S. Mitchell and E. Link (eds.) *"Impact of Public Policy on Drug Innovation and Pricing"*, American University, Washington.

Griliches, Z. (1957) *"Hybrid Corn: An Explanation in the Economics of Technological Change"*, Econometrica, October.

Griliches, Z. (1958) *"Research Costs and Social Returns: Hybrid Corn and Related Innovations"*, Journal of Political Economy, October.

Griliches, Z. (1963) *"The Sources of Measured Productivity Growth: United States Agriculture, 1940-1960"*, Journal of Political Economy, August.

Griliches, Z. (1964) *"Research Expenditures, Education and Aggregate Agricultural Production Function"*, American Economic Review, December.

Griliches, Z. (1973) *"Research Expenditures and Growth Accounting". In:* B.R. Williams (ed.) *"Science and Technology in Economic Growth"*, International Economic Association.

Gruber, W. and Marquis, D. (eds.) (1969) *"Factors in Transfer of Technology"*, M.I.T. Press.

Hamberg, D. (1959) *"Production, Functions, Innovations and Economic Growth"*, Journal of Political Economy, June.

Harrod, R.F. (1948) *"Towards a Dynamic Economics"*, Macmillan.

Harrod, R.D. (1961) *"The 'Neutrality' of Improvements"*, Economic Journal, June.

Hayami, Y., Ruttan, V.W. (1971) *"Agricultural Development: An International Perspective"*, Baltimore: Johns Hopkins Press.

Hicks, J.R. (1932) *"The Theory of Wages"*, Macmillan Co., New York.

Hicks, J.R. (1973) *"Capital and Time: A Neo-Austrain Theory"*, Oxford: Clarendon Press.

Hitch, C.J. (1958) *"The Character of Research and Development in a Competitive Economy"*, Rand Corporation, May.

Howe, J.D., and McFetridge, D.G. (1976) *"The Determinants of R&D Expenditures"*, The Canadian Journal of Economics, February.

I.E.A. (1973) *"Science and Technology in Economic Growth"*, B.R. Williams (ed.) New York, Wiley.

Jewkes, J., Sawers, D., and Stillerman, R. (1969) *"The Sources of Invention"*, Norton, New York, 2nd ed.

Johnston, K.R.H. (1970) *"Patents and Economic Growth"*. *In:* M. Goldsmith (ed.) *"Technological Innovation and the Economy"*, Wiley-Interscience.

Jorgenson, D.W. (1963) *"Capital Theory and Investment Behaviour"*, American Economic Review, May.

Jorgenson, D.W., and Griliches, Z. (1967) *"The Explanation of Productivity Change"*, Review of Economic Studies, July.

Kaldor, N., and Mirlees, J.A. (1961-2) *"Growth Model with Induced Technical Progress*, Review of Economic Studies, Vol. 29.

Kamien, M., and Schwartz, N. (1975) *"Market Structure and Innovations: A Survey"*, Journal of Economic Literature, March.

Kendrick, J. (1956) *"Productivity Trends, Capital, and Labour"*, Review of Economics and Statistics, August.

Kennedy, C. (1962) *"Harrod on Neutrality"*, Economic Journal, March.

Kennedy, C. (1964) *"Induced Bias in Innovation and the Theory of Distribution"*, Economic Journal, September.

Kennedy, C. (1973) *"A Generalisation of the Theory of Induced Bias in Technical Progress"*, Economic Journal, March.

Kennedy, C., and Thirlwall, A.P. (1972) *"Technical Progress: A Survey"*, Economic Journal, March.

Klein, B.H., and Meckling, W.H. (1958) *"Application of Operations Research to Development Decisions"*, Operations Research, May-June.

Knoppers, A.T. (1970) *"A Management View of Innovation"*. *In:* M. Goldsmith (ed.) *"Technological Innovation and the Economy"*, Wiley-Interscience.

Kuznets, S. (1930) *"Secular Movements in Production and Prices"*, Houghton Mifflin Co., Boston.

Kuznets, S. (1962) *"Inventive Activity: Problems of Definition and Measurement". In:* R. Nelson (ed.) *"Rate and Direction of Inventive Activity: Economic and Social Factors"*, Princeton University Press.

Leonard, W.N. (1971) *"Research and Development in Industrial Growth"*, Journal of Political Economy, March/April.

Lovell, C. (1969) *"Biased Technical Change and Factor Shares in United States Manufacturing"*, Quarterly Review of Economics and Business, Autumn.

McCain, R. (1972) *"Induced Technical Progress and the Price of Capital Goods"*, Economic Journal, September.

McCain, R. (1974) *"Induced Bias in Technical Innovation Including Product Innovation in a Model of Economic Growth"*, Economic Journal, December.

Machlup, F. (1962) *"The Supply of Inventors and Inventions". In: "The Rate and Direction of Inventive Activity"*, National Bureau of Economic Research, Princeton University Press.

MacLaurin, W.R. (1950) *"The Process of Technological Innovation: The Launching of a New Scientific Industry"*, American Economic Review, Vol. 60.

McLaurin, W.R. (1954) *"Technological Progress in Some American Industries"*, American Economic Review, May.

Mansfield, E. (1961) *"Technical Change and the Rate of Imitation"*, Econometrica, October.

Mansfield, E. (1965) *"Rates of Return from Industrial Research and Development"*, American Economic Review, May.

Mansfield, E. (1968) *"Industrial Research and Technological Innovation"*, W.W. Norton & Co., New York.

Mansfield, E. (1968) *"The Economics of Technological Change"*, W.W. Norton & Co., New York.

Mansfield, E. (1971) *"Technological Change"*, W.W. Norton & Co., New York.

Mansfield, E. (1973) *"Determinants of the Speed of Application of New Technology". In:* B.R. Williams (ed.) *"Science and Technology in Economic Growth",* International Economic Association.

Mansfield, E., Rapoport, J., *et al.* (1977) *"The Production and Application of New Industrial Technology",* W.W. Norton & Co., New York.

Mansfield, E., Rapoport, J., Romeo, A., Wagner, S., and Beardsley, G. (1977) *"Social and Private Rates of Returns from Industrial Innovation",* Quarterly Journal of Economics, May.

Massel, B.F. (1960) *"Capital Formation and Technological Change in U.S. Manufacturing",* Review of Economics and Statistics, May.

Merton, R. (1935) *"Fluctuations in the Rate of Industrial Invention",* Quarterly Journal of Economics, May.

Methews, R.C.O. (1973) *"The Contribution of Science and Technology to Economic Development". In:* B.R. Williams (ed.) *"Science and Technology in Economic Growth",* International Economic Association.

Mill, J.S. (1848) *"Principles of Political Economy",* Parker and Company.

Minasian, J.R. (1962) *"The Economics of Research and Development". In:* R. Nelson (ed.) *"Rate and Direction of Inventive Activity",* Princeton University Press.

Minasian, J.R. (1969) *"Research and Development, Production Functions, and Rates of Return",* American Economic Review, May.

Mueller, W. (1962) *"The origins of the Basic Inventions Underlying DuPont's Major Product and Process Innovations, 1920-1950". In:* R. Nelson (ed.) *"The Rate and Direction of Inventive Activity",* Princeton University Press.

Nabseth, L., and Ray, G. (eds.) (1974) *"The Diffusion of New Industrial Processes: An International Study",* Cambridge University Press.

Nadiri, M.I. (1970) *"Some Approaches to the Theory and Measurement of Total Factor Productivity: A Survey"*, Journal of Economic Literature, December.

Nadiri, M.I. (1979) *"Contributions and Determinants of Research and Development Expenditures in the U.S. Manufacturing Industries"*, Department of Economics, New York University, working paper No. 79-16.

Nadiri, M.I., and Bitros, G. (1979) *"Research and Development Expenditure and Labor Productivity". In:* J. Kendrick and B. Vaccana (eds.) *"New Developments in Productivity Measurement"*, National Bureau of Economic Research; Ballinger.

Nadiri, M.I., and Rosen, S. (1973) *"A Disequilibrium Model for Factors of Production"*, National Bureau of Economic Research; Columbia University Press.

National Science Foundation (Annual) *"Research and Development in Industry"*, Washington, D.C., U.S. Government Printing Office.

Nelson, R.R. (1959a) *"The Economics of Invention: A Survey of the Literature"*, Journal of Business, Vol. 32.

Nelson, R.R. (1959b) *"The Simple Economics of Basic Scientific Research"*, Journal of Political Economy, June.

Nelson, R.R. (ed.) (1962) *"Rate and Direction of Inventive Activity: Economic and Social Factors", Princeton University Press.*

Nelson, R.D., Peck, M.J., and Kalachek, E.D. (1967) *"Technology, Economic Growth, and Public Policy"*, The Brookings Institution.

Nordhaus, W.D. (1967) *"The Optimal Rate and Direction of Technical Change". In:* K. Shell (ed.) *"Essays on the Theory of Optimal Economic Growth"*, M.I.T. Press.

Nordhaus, W.D. (1973) *"Some Skeptical Thoughts on the Theory of Induced Innovation"*, Quarterly Journal of Economics, May.

Parker, W. (1961) *"Economic Development in Historical Perspective"*, Economic Development and Cultural Change, October.

Pavitt, K. (1970) *"Performance in Technological Innovation in the Industrially Advanced Countries". In:* M. Goldsmith (ed.) *"Technological Innovation and the Economy"*, Wiley-Interscience.

Pavitt, K., and Wald, S. (1971) *"The Conditions for Success in Technological Innovation"*, OECD, Paris.

Rasmussen, J.A. (1973) *"Applications of a Model of Endogenous Technical Change to U.S. Industry Data"*, Review of Economic Studies, April.

Ricardo, D. (1821) *"Principles of Political Economy"*, Dent.

Robinson, J. (1938) *"The Classification of Inventions"*, Review of Economic Studies, February.

Romeo, A. (1975) *"Interindustry and Interfirm Differences in the Rate of Diffusion and Innovation"*, Review of Economics and Statistics, August.

Rosegger, G. (1977) *"Diffusion of Technology in Industry". In:* B. Gold (ed.) *"Research, Technological Change, and Economic Analysis"*, Lexington.

Rosenberg, N. (ed.) (1971) *"The Economics of Technological Change"*, Penguin. *

Rosenberg, N. (1976) *"Perspectives on Technology"*, Cambridge University Press, Cambridge, Mass.

Ruttan, V. (1956) *"The Contribution of Technological Progress to Farm Output, 1950-75"*, Review of Economics and Statistics, Vo. 38.

Ruttan, V. (1959) *"Usher and Schumpeter on Invention, Innovation and Technological Change"*, Quarterly Journal of Economics, November.

Salters, W.E.G. (1960) *"Productivity and Technical Change"*, Cambridge University Press, Cambridge, Mass.

Samuelson, P.A. (1965) *"A Theory of Induced Innovation Along Kennedy-Weizacker Lines"*, Review of Economics and Statistics, November.

Sanders, B.S. (1962) *"Some Difficulties in Measuring Inventive Activity". In:* R. Nelson (ed.) *"Rate and Direction of Inventive Activity"*, Princeton University Press.

Sanow, K. (1959) *"Development of Statistics Relating to Research and Development Activities in Private Industry". In: "Methodology of Statistics on Research and Development"*, National Science Foundation, Washington, D.C.

Saul, S.B. (ed.) (1970) *"Technological Change: The United States and Britain in the 19th Century"*, Methuen.

Scherer, F. (1965) *"Size of Firm, Market Structure, Opportunity and the Output of Potential Inventions"*, American Economic Review, December.

Schmookler, J. (1952) *"The Changing Efficiency of the American Economy, 1869-1938"*, Review of Economics and Statistics, August.

Schmookler, J. (1954a) *"Invention, Innovation, and Competition"*, Southern Economic Journal, April.

Schmookler, J. (1954b) *"The Level of Inventive Activity"*, Review of Economics and Statistics, May.

Schmookler, J. (1959) *"Bigness, Fewness, and Research"*, Journal of Political Economy, December.

Schmookler, J. (1962a) *"Changes in Industry and in the State of Knowledge as Determinants of Industrial Invention". In:* R. Nelson (ed.) *"The Rate and Direction of Inventive Activity: Economic and Social Factors"*, NBER, Princeton University Press.

Schmookler, J. (1962b) *"Economic Sources of Inventive Activity"*, Journal of Economic History, March.

Schmookler, J. (1965a) *"Technological Change and Economic Theory"*, American Economic Review, May.

Schmookler, J. (1965b) *"Catastrophe and Utilitarianism in the Development of Basic Science". In:* R. Tybout (ed.) *"Economics of Research and Development"*, Ohio State University Press; reprinted in his *"Patents, Invention, and Economic Change"*, Harvard University Press, 1972.

Schmookler, J. (1966) *"Invention and Economic Growth"*, Cambridge, Mass., Harvard University Press.

Schmookler, J. (1972) *"Technological Change and the Law of Industrial Growth". In:* his *"Patents, Invention, and Economic Change"*, Harvard University Press.

Schmookler, J. (1972) *"Patents, Invention, and Economic Change"*, Harvard University Press.

Schmookler, J., and Brownlee, O.H. (1963) *"Determinants of Inventive Activity"*, American Economic Review, September.

Schumpeter, J. (1934) *"The Theory of Economic Development"*, Harvard University Press.

Schumpeter, J. (1939) *"Business Cycles: A Theoretical, Historical, and Statistical Analysis of the Capitalist Process"*, McGraw-Hill.

Schwartzman, D. (1976) *"Innovation in the Pharmaceutical Industry"*, Johns Hopkins University Press.

Silk, L. (1960) *"The Research Revolution"*, McGraw-Hill.

Solo, C.S. (1951) *"Innovation in the Capitalist Process: A Critique of the Schumpeterian Theory"*, Quarterly Journal of Economics, Vol. 65.

Solo, R.A., and Rogers, E.M. (eds.) (1972) *"Inducing Technological Change for Economic Growth and Development"*, Michigan State University Press.

Solow, R. (1957) *"Technological Change and the Aggregate Production Functions"*, Review of Economics and Statistics, XXXIX, No. 3, August.

Solow, R. (1958) *"A Skeptical Note on the Constancy of Relative Shares"*, American Economic Review, September.

Stafford, A.B. (1952) *"Is the Rate of Invention Declining?"*, American Journal of Sociology, May.

Sutherland, A. (1959) *"Diffusion of an Innovation in Cotton Spinning"*, Journal of Industrial Economics, March.

Taylor, C., and Silberston, Z. (1973) *"The Economic Impact of the Patent System"*, Cambridge University Press.

Terleckyj, N. (1974) *"The Effects of R&D on Productivity Growth of Industries: An Exploratory Study"*, National Planning Association, Washington, D.C.

U.S. Department of Commerce, Bureae of the Census (Annual) *"Annual Survey of Manufacturers"*, Washington, D.C., U.S. Government Printing Office.

U.S. Department of Commerce, Bureau of the Census (Annual) *"Statistical Abstract of the United States"*, Washington, D.C., U.S. Government Printing Office.

U.S. Department of Commerce (Monthly) *"Survey of Current Business"*, Washington, D.C., U.S. Government Printing Office.

U.S. Department of Commerce, Bureau of the Census (1976) *"1972 Census of Manufacturers"*, Washington, D.C., U.S. Government Printing Office.

U.S. Department of Labour, Bureau of Labour Statistics (1973) *"Employment and Earnings, United States, 1909-72"*, Washington, D.C., U.S. Government Printing Office.

Usher, A.P. (1951) *"Historical Implications of the Theory of Economic Development"*, Review of Economics and Statistics, Vol. 33.

Usher, A.P. (1954) *"A History of Mechanical Inventions"*, Harvard University Press.

Usher, A.P. (1955) *"Technical Change and Capital Formation", In: "Capital Formation and Economic Growth"*, Universities - National Bureau Committee for Economic Research.

Villard, H.H. (1958) *"Competition, Oligopoly and Research"*, Journal of Political Economy, Vol. 66.

Williams, B.R. (ed.) (1973) *"Science and Technology in Economic Growth"*, Proceedings of IEA Conference in Austria, N.Y. Wiley.

Wolfson, R.J. (1958) *"The Economic Dynamics of Joseph Schumpeter"*, Economic Development and Cultural Change, Vol. 7.