SCIENTIFIC RESEARCH, INNOVATION AND ECONOMIC GROWTH : A POSSIBLE RELATIONSHIP

by

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CHAPTER 1

INTRODUCING RESEARCH ECONOMICS

"Take interest, I implore you, in those sacred dwellings which are designated by the expressive term: laboratories. Demand that they be multiplied, that they be adorned. These are the temples of the future - temples of well-being and happiness. There it is that humanity grows greater, stronger, better."

Louis Pasteur.

1.1 GENERAL INTRODUCTION

Resources devoted to science, or rather to "new science" or research and development and related technical activities have undergone a remarkable rate of increase over the past two decades throughout most of the world. This phenomenon has been symptomatic, not only of the development of the majority of nations in the "western world" but also of the Soviet bloc, and furthermore, all the indications are that this expansion of scientific activities will continue throughout the present decade. As a whole, attempts at measurement of these activities have proved unsatisfactory in many respects. Those that have achieved a reasonable degree of accuracy (for example, measurements in terms of expenditure on, and manpower devoted to, research and development) present the observer with concrete facts as to this rate of increase.

The National Science Foundation of America for example has estimated that research and development expenditures in the United States have increased from $5.4 billion in 1953 to an estimated $10 billion in 1957, and to roughly $20 billion in 1964.[1] More recent attempts at measurement are illustrative that the future promises even greater advances. For example, in Table 1[2] are shown the increases in expenditure devoted to research and development in eight major countries of the world. These increases are considerable, particularly in the United States and Soviet Russia. Table 2 has been included to

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1. National Science Foundation, Proceedings of a Conference on Research and Development and its Impact on the Economy. United States Government Printing Office, Washington, 1958, p.1

2. See Table 1, page 10 of this section.

achieve some measure of comparability of estimates and shows absolute totals for estimated expenditure on research and development by the United States, the United Kingdom and Western Europe in 1962.[1] The United States, with an expenditure of $ 93.7 per capita on research and development, far outmatches the others in the extent of its research and development effort.

In making comparisons of increases in expenditures over any period it is always useful to relate such increases to other economic indices. For this reason Table 1 and Table 3 [2] both include data on research and development expenditures related to gross national product, a primary index of measurement in any country. From these two tables it can be seen that even when national research expenditures are related to other indices of measurement, the size of the research effort and its increase is remarkable. Two technically advanced Western countries, Britain and the United States are at present devoting more than two per cent of their gross national product to scientific research and technical development; and the evidence of published Soviet data on national income and research expenditures indicates that the Soviet Union is also committed to approximately the same extent.

1.2 BACKGROUND OF STUDY

On the evidence available then, [3] there would appear to be some justification for a closer study of the research and development effort. In particular, governments of the world are becoming increasingly concerned about their national efforts in scientific research and development, largely because many governments are paying increasingly large sums to support research and development. The proportion of national budget expenditures devoted to research and development is high, as the state is the principal source of finance for research activities in most countries. The National Science Foundation, for example has estimated that during the United State's financial year 1961 - 62, 11 per cent of the Federal Budget expenditure was devoted to the financing of research and development.[4] This point is amplified in Table 4, where research and development expenditure in the U.S.A., Western Europe and Britain during 1962 is classified according to performing sectors and the source of research funds.[5]

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1. See page 11 of this section.
2. See page 12 of this section.
3. A preliminary estimate of the South African research effort indicates that during 1964/65, the Republic devoted approximately 0.5% of the gross National Product (market prices) to research and development activities.
4. Op. cit. p. 123
5. See p. 13 of this section.

From the latter, the overwhelming proportion of research funds originating from the government can readily be seen; for example 63 per cent of gross expenditure on research and development in the U.S.A. is government financed, with Western Europe and the United Kingdom showing similar high percentages for government-financed research efforts.

One important result of the above concern on the part of governments is that the concept of science policy has made its appearance, replacing an older idea that science is a purely cultural activity which should be supported as such but which should not be expected to yield much in the way of definable returns. A further source of heightened interest on the part of governments with research and development activities is the existence of a general, and, until recently, a rather vague feeling that an adequate national effort in research and development is now essential to the well-being of an industrialized society.

This concern has led inter alia to the creation in many countries of government bodies concerned with the national science and scientific research and development effort. Belgium now has a National Council for Science Policy, France a General Delegation for Scientific and Technical Research, the United Kingdom an office of the Minister of Science, and the United States a President's office for Science and Technology. Within the past few years, the Italian, Swedish, West German, and South African Governments have been a few of the countries who have all established special departments or councils to deal with questions of science policy.

However, the recent interest aroused in national expenditures on research and development has not been confined to matters of science policy alone. If society devotes a considerable amount of its resources to any particular activity, economists will want to look into this allocation and get an idea of the magnitude of the activity, its major breakdown, and its relation to other activities. The central theme in economic science has traditionally been concerned with the allocation of scarce resources among competing ends, and research and development activity presents no exception. Research and development activity, on the scale it has become in recent years, is a major competitor for scarce resources, vying with industry and other sectors of the economy for the resources of land, capital and labour, particularly skilled and scientific manpower.

Thus, following upon the rapid increase in the scale of research and development activity, but lagging somewhat behind, has come a significant shift in the emphasis of economic thought. Attendant on the increased attention to the problems of economic growth, has been a rising interest in the economic consequences of research, development and innovational change. This change in emphasis is probably long overdue. Indeed as Professor Jewkes [1)] points out:-

> "Future historians of economic thought will doubtless find it remarkable that so little systematic attention was given in the first half of this century to the causes and consequences of innovation. Material progress, it had long been taken for granted, was bound up with technical advance, in turn with change, variety and novelty; but whence this novelty, how closely it was related to rising standards of living, whether and how it might be stimulated or stifled : all this ground remained largely untrodden by the economic historian or the economic theorist. The comparative disregard of one, if not the mainspring of economic progress is not altogether mysterious. The subject is not one to which economic analysis is easily applied; it may yet prove impossible to apply it so. And the descriptive economist finds his way blocked by the complexity of the subject; the growing specialization in science and technology presents to the outside observer a barrier even to the simplest understanding of what is occurring there.
>
> A more important reason is simply that economists have been occupied in other ways where it seemed easier to reach results or where the immediate or practical value of their ideas seemed to be greater ... all this seems to have changed or to be in the process of changing and, with the intriguing capacity which groups of scholars and scientists seem to possess, of spontaneously wheeling and pursuing a new object of greater intrinsic interest, the study of economic growth, and with it that of change and innovation, has become a major preoccupation."

The most obvious reason for this 'apparent neglect' has been the dearth of reliable statistics. No matter how eager the theorist, and there have been many through the years interested in the subject of change as a major economic variable, he was confined by the lack of factual data to rather limited and abstract generalizations and even to complete

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1. Jewkes, Sayers and Stillerman, <u>The Sources of Invention</u>, Macmillan & Co. Ltd., London, 1960, p. 3.

dismissal of the subject. Statistics on research and development and related activities are still far from perfect, but at least a concerted effort to overcome these inadequacies is under way, for example through the efforts of such bodies as the Organization for Economic Co-operation and Development in Paris, the National Science Foundation in America, and now the Council for Scientific and Industrial Research in South Africa.

As mentioned, the primary factor (from the economic viewpoint at least) responsible for the awakened interest in research and development and the subsequent collection of statistical data, has arisen from the question of what we can expect to "get out of" the research effort as measured in terms of national expenditures on research and development activities. To the eye of the observer, there is no doubt that the application of science to agriculture, industry, medicine and war has transformed our everyday life, and as one writer has said, may even end it. This extraordinary power of applied science to transform existing methods of production and to create entirely new commodities, has led a good many people to argue that this is the key factor in economic growth, and that by simply increasing expenditure on research and development we can expect a proportionate increase in economic growth. However, the influence of research on economic progress is by no means as self-evident as is sometimes suggested. The direct result of research is, in the first place, knowledge and whether or not this knowledge is pursued to lead to farther-reaching conclusions depends on a number of circumstances. Not every expenditure on research should be expected to produce an immediate increase of the national product, or, in fact, to have any effect on output at all. Indeed, if we have a look at the expenditure on research and development in various countries, and relate that expenditure to the level of output per head, we find that there is no significant positive relationship between the research and development rate and the growth of output rate. Indeed, Britain and the United States, which are clear leaders in research and development expenditure, are almost at the bottom of the growth rate league in the industrial world, whereas countries like Germany and France, which have not, since the war, had a high place in the research league, have very high places in the growth rate. For example, discussing the rapid increase of research expenditure in Britain over the past decade, an extract from Business, 1964, points out:-

> "One disquieting feature remains: a lot more money spent on research does not seem to have triggered off anything like a proportionate increase in Gross National Product or productivity. Perhaps the criticism that industry

is reluctant often to apply known technology may be true. Let's press for a little more light on the relationship between research and development expenditure and productivity increases."

The Economist of August 28th, 1965, has something to say in the same vein:-

"..... governments are only starting to explore one of the biggest economic riddles of the decade - the effect of science on industry ... But does it work? Is it virtuous to spend a high proportion of gross national product on research, and we spend roughly the same proportion now as the Americans; why do the unvirtuous Germans and Japanese flourish with the absolute minimum of spending in science? What are the economics of innovation? The fact that Britain has upped the proportion of G N P that goes on research with no visible results does not necessarily prove science is Bunk but it may mean that the effort is being made in the wrong places. Scientists have pleaded for years for an investigation into the impact of science on the economy."

It is clear then that rash statements as to the effect of scientific research and development on significant economic variables, in particular that of economic growth, should be avoided since, in the light of the available evidence: "The idea that we can treat research and development as the chariot of economic progress is misleading. The idea that the velocity of this chariot will be a direct result of the current expenditure on research and development is particularly misleading."[1)]

Mistakes or false impressions like the above were hardly surprising in light of the absence of substantial theory and quantitative data in the field. However, in order for the economy to derive the greatest benefit from research and development efforts, we must fully understand the process by which an achievement in science finally results in an achievement in economics or in increased income if it does so at all. As yet, there is no specific body of general theory to assist the economist in this field. An overall comprehension of the interrelationship between economic and scientific developments can, at present, be of a general character only and much highly complex research is required on the economic value of new scientific and technological knowledge before a basis can be established upon which to build a general theory. Science and technology

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1. Professor Williams B.R., Faculty of Economic and Social Studies, University of Manchester, note of an address given to the Parliamentary and Scientific Committee, General Committee, London, 21 July, 1964, p.2.

represent fields in which the economist frequently tends to feel uncomfortable, but are factors essential to the science of economics both on a national or on a more micro-economic scale.

Although, then, the present state of the general economic theory on scientific research presents rather a dismal picture, one encouraging fact emerges: since Schumpeter's theory of innovational change [1], the importance of technological innovation to economic growth has been increasingly stressed, and a much needed emphasis is now being placed on the introduction of science and technology into the economy. Too little attention, however, has till recently been paid to the precise meanings of these concepts or to the possible ways they may act to bring about economic growth. The only sound knowledge of the process has consisted of vague theoretical postulates and hypotheses which have not been subjected to empirical tests. Certain areas of agreement and common themes have emerged among both economists and businessmen. They know relatively little that is specific and concrete about the direct economic effect of changes in products or processes as a result of research and development activities; they know that not much specific and validated data has been collected on the subject and that the methodology for doing so is still groping and fallible.

Since the turn of the 'sixties, however, a massive overall attack has been launched not so much on the "ignorance" of the state of the economic theory in the field of scientific research - economic growth relationships, but on the methodology of building up that theory. The primary result of the voluminous flow of literature has been an identification of the variables involved, mathematical attempts to isolate them, and suggestions as to the methodology of further study, at both the micro- and macro-economic level.

For example, the authors of a recent report of the Organisation for Economic Co-operation and Development [2] have found that "insufficient interest has been shown in the past by economists in the 'residual factors' which contribute towards economic growth." These factors such as education, research and development, and organisation are regarded as "exogenous" to most of the models

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1. Schumpeter J.A., The Theory of Economic Development, Harvard Economic Studies No. XLVI, Cambridge, Massachusetts, 1934.
2. Science Economic Growth, and Government Policy, Economic Co-operation and Development, Paris, 1964, p.3.

evolved by economists to analyse, and explain economic behaviour. Yet these 'exogenous' factors might explain a large part of economic growth. The authors go on to say: "There is, then, a need to investigate the mechanisms of technological and social processes in order to arrive at a more complete explanation of economic growth. The nature of the problems which must be attacked is such that one should not expect a striking leap forward. Methods of economic analysis must be combined with those of psychology, business organisation, and political science. The primary need at present is for empirical fact finding."

To give another example, Robert Solow[1)] writes in his conclusion that "capital formation is not the only source of growth in productivity. Investment is at best a necessary condition for growth, surely not a sufficient condition. Recent study has indicated the importance of such activities as research, education, and public health. But while economists are now convinced of the significance of these factors in the process of economic growth, we are still a long way from having any quantitative estimate of the pay-off to society of resources devoted to research, education and improvements in allocative efficiency. Since such estimates must form the foundation for a rational allocation of resources in the interest of economic growth, their provision by hook or by crook, presents a research problem of great theoretical and practical interest."

1.3 OBJECTS AND SCOPE OF STUDY

So it can be seen, given the importance science and technology play in today's economy that the above identifications establish and the emphasis placed on economic growth and fuller employment of the labour force, an advancement in our understanding of the relationship between science, technology and economic growth promises substantial dividends.

Attempts to meet this need have given rise to a new field of economic study, that of research economics which is undergoing extensive investigation in many countries of the world. In South Africa, the Industrial Economics Division of the Council for Scientific and Industrial Research assumed official responsibility for such a study in 1964. This dissertation is in the nature of a by-product of the

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1. Solow R, "Technical Change and the Aggregate Production Function," Review of Economics and Statistics, Volume 39, August, 1957, p.312 - 320.

above study, arising from a desire to form a closer acquaintance with some of the concepts encountered in the field of research economics.

As such the following chapters represent an attempt to arrive at a better understanding of the above relationship, concentrating more specifically on the micro-economic as opposed to the national level of study. To cover the entire field of science - economic growth relationships would clearly be impossible in an essay of this nature, so it is intended to concentrate on two main lines of study. Firstly, some attention will be paid to the meanings of the various concepts encountered in the field of research economics, and to the possible ways, (in particular, that of technical innovation) in which they may act to bring about economic growth; and secondly, to indicate possible methods of study by which the relationship between scientific research and technical innovation may be firmly established. In the process, a brief account of the history and development of the research effort in South Africa - orientated towards the probable consequences of South African research - will be given.

The conclusions to be drawn from a study of this rather limited nature will have no significant impact on general economic theory; that is not the intention of this thesis. Rather, it is hoped that they will give some grounds for the recently aroused interest on the part of economic literature in research and development activity; and, in particular, to some justification of that interest, and possibly to act as a guide to the nature of further similar investigations. My somewhat lofty excuse for the task could possibly be as follows:

> " The study of these weighty and complex affairs is, therefore, at the elementary stage in which no one need be ashamed of making a mistake or being forced to go back along his tracks: the only inexcusable error is that of rushing to premature final conclusions and hanging onto them too possessively. What is needed is first more actual knowledge about technical and economic change[1] .

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1. Jewkes, Sayers and Stillerman, op. cit. p. 8

TABLE 1.

TOTAL EXPENDITURE ON SCIENTIFIC AND TECHNICAL RESEARCH

	YEAR	FEDERAL REPUBLIC OF GERMANY.		BELGIUM		UNITED STATES OF AMERI-CA.	FRANCE		JAPAN		NETHERLANDS		UNITED KINGDOM		U. S. S. R.	
		D. M.	$	B. fr.	$	$	F. fr.	$	YEN	$	Fl.	$	£	$	R	$
ABSOLUTE FIGURES (National currency and dollars, in thousand-millions)	1957	2.077	0.5192	-	-	8.610	-	-	60.19	0.1680	-	-	-	-	1.630	1.467
	1958	2.443	0.6107	-	-	10.03	-	-	79.03	0.2206	-	-	0.4778	1.339	1.820	1.638
	1959	2.935	0.7337	2.635	0.05468	11.07	2.230	0.4549	148.9	0.4157	0.5357	0.1488	-	-	2.730	2.457
	1960	3.536	0.8840	3.168	0.06574	12.62	2.852	0.5818	184.4	0.5149	-	-	-	-	3.200	2.880
	1961	3.867	0.9667	3.920	0.08134	14.04	3.436	0.7009	-	-	-	-	0.6340	0.1777	3.800	3.420
	1962	-	-	4.435	0.09203	15.00	-	-	-	-	-	-	-	-	-	-
	1963	-	-	4.875	0.1011		-	-	-	-	-	-	-	-	-	-
AS A PERCENTAGE OF NATIONAL INCOME	1957	1.25		-		2.36	-		0.73		-		-		1.45	
	1958	1.38		--		2.75	-		0.94		-		2.58		1.44	
	1959	1.53		0.52		2.78	1.14		1.54		1,71		-		2.01	
	1960	1.61		0.71		3.06	1.32		1.61		-		-		2.18	
	1961	1.61		0.83		3.31	1.47		-		-		2.93		2.42	
AS A PERCENTAGE OF GROSS NATIONAL PRODUCT. (at factor cost)	1957	1.13		-		2.12	-		-		-		-		-	
	1958	1.24		-		2.45	-		-		-		2.35		-	
	1959	1.38		0.50		2.49	1.02		-		1.52		-		-	
	1960	1.45		0.57		2.74	1.18		-		-		-		-	
	1961	1.44		-		2.95	1.32		-		-		2.65		-	
AS A PERCENTAGE OF GROSS NATIONAL PRODUCT (at market prices)	1957	0.97		-		1.94	-		0.59		-		-		-	
	1958	1.07		-		2.25	-		0.79		-		2.08		-	
	1959	1.21		0.46		2.29	0.86		1.24		1.39		-		-	
	1960	1.25		0.52		2.50	1.00		1.32		-		-		-	
	1961	1.25		-		2.70	1.11		-		-		2.37		-	
PER CAPITA EXPENDITURE IN 1961 (in national currency units and dollars)		68.78	17.19	425.9	8.838	76.41	74.76	15.25	1978	5.523	47.21	13.11	12.01	33.66	17.43	5.69

SOURCE: UNESCO/NS/ROV/24 Paris 22 February 1965. Comparative Bibliographical study on National Expenditure for Scientific and Technical Research. p.13

TABLE 2.

ESTIMATED GROSS EXPENDITURE ON RESEARCH AND DEVELOPMENT, 1962.

	Currency	National Currency	$ U S (millions) Official Exchange Rate	Population (millions)	R and D Expenditure Per Capita $ U S Official Exchange Rate
UNITED STATES	$ Million	17 531	17 531	187	93.7
WESTERN EUROPE *	-	-	4 360	176	24.8
BELGIUM	Million Francs	6 625	133	9	14.8
FRANCE	Million Francs	5 430	1 108	47	23.6
GERMANY	Million D M	4 419	1 105	55	20.1
NETHERLANDS	Million Florins	860	239	12	20.3
UNITED KINGDOM	£ Million	634	1 775	53	33.5

* Belgium, France, Germany, Netherlands, United Kingdom.

SOURCE: FREEMAN C. AND YOUNG A. The Research and Development Effort in Western Europe, North America, and the Soviet Union, Organization for Economic Co-operatio and Development, Paris 1965, p. 71.

TABLE 3.

ESTIMATED GROSS EXPENDITURE ON RESEARCH AND DEVELOPMENT[1)] AND GROSS NATIONAL PRODUCT, 1962.

	Currency	GERD	G N P [2)] at Market Price [3)]	GERD as % of G N P at Market Price[3)] %
UNITED STATES	$ Million	17 531	557 590	3.1
BELGIUM	Million Francs	6 625	646 200	1.0
FRANCE	Million Francs	5 430	356 300	1.5
GERMANY	Million D M	4 419	354 500	1.3
NETHERLANDS	Million Florins	860	48 090	1.8
UNITED KINGDOM	£ Million	634	28 566	2.2

1. GERD
2. Gross National Product.
3. If G N P is taken at factor cost instead of Market Price the ratios are:

United States 3.5%

Belgium 1.2%

France 1.8%

Germany 1.5%

Netherlands 1.7%

United Kingdom 2.5%

SOURCE: FREEMAN, C and YOUNG A.: The Research and Development Effort in Western Europe, North America and the Soviet Union, op. cit. p. 71.

TABLE 4.

ESTIMATED GROSS EXPENDITURE ON RESEARCH AND DEVELOPMENT BY SECTORS OF THE ECONOMY, 1962.

	PERFORMANCE			SOURCE OF FUNDS		
	Business Enterprise Sector	Higher Education Sector	Government and Non-Profit Sectors	Business Enterprise Sector	Higher Education Sector	Government and Non-Profit Sectors
UNITED STATES	71	10 1)	19 3)	35	2)	63
WESTERN EUROPE *	59	12	29	43	(X)	57
BELGIUM	65	13	22	63	(X)	37
FRANCE	48	14 2)	38	30	4)	70
GERMANY	61	20	19	60	(X)	40
NETHERLANDS	60	14	26	65	(X)	35
UNITED KINGDOM	63	5	32	36	(X)	64

* Belgium, France, Germany, Netherlands, United Kingdom, at official exchange rates.

(X) Negligible

1. Including federal contract centres (3%)
2. Including C N R S (5%)
3. Non-profit 3%, Government 16%.
4. Included in "government and non-profit sectors".

SOURCE: FREEMAN, C. and YOUNG, A. : The Research and Development Effort in Western Europe, North America and the Soviet Union, Op. cit. p. 72.

CHAPTER 2

ECONOMIC GROWTH : CHARACTER AND CAUSES

> "The intensive study of the problem of economic development has had one discouraging result: it has produced an ever lengthening list of factors and conditions, of obstacles and prerequisites. The direction of the inquiry has proceeded from thoroughly objective, tangible, and quantitative phenomena to more and more subjective, intangible and unmeasurable ones."
>
> A.O. Hirschman [1)]

2.1 CHARACTERISTICS OF GROWTH

There are two main problems in the field of economic growth; the one is how to begin (and sustain) the process in those countries which remain very poor; the other is how to influence the rate of growth of developed countries. The study of the former has become so important today that it covers a field of its own, commonly referred to as "the economics of development", and differs vastly in range and complexity from the study of the growth of developed lands. It is not the intention of this essay to study the economics of development, but rather to concentrate on certain aspects of economic growth in countries falling within the category of "developed" economies. In other words, the focus of this study will be on the relationship between scientific research and what we shall call "modern economic growth" - the progress of a modern, industrialised western economy.

First, let us be clear on what is meant by economic growth. According to Simon Kuznets,[2)] the distinctive feature of modern economic growth is the frequent combination of high rates of growth of the total population and of per capita product, implying even higher rates of growth of total product. In other words, the most common over-all measure of a country's economic performance is total output per capita - on the realistic assumption, of course, that it is also a relative index of productivity per worker, since the

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1. Hirschman, A.O. The Strategy of Economic Development. Yale University Press New Haven 1958 p.1
2. Kuznets, S. Post-War Economic Growth - Four Lectures, Harvard University Press, Cambridge, Massachusetts. 1964 p. 36

variation in the ratio of labour force to total population is regarded as being fairly limited. It is generally agreed then, that if a country enjoys an increased per capita income, or produces a greater per capita product or output, that country is experiencing economic growth. Having determined what is meant by economic growth, the next question to be considered is: what causes that growth?

2.2 AGENTS OF GROWTH

Since we are considering the progress of a country which is over the threshold of development, and is experiencing modern economic growth, we are concerned only with the agents, or determinants of growth. It is assumed that the "conditions" for growth have been met and are present. Examples of such conditions are a stable political situation, with minimum standards in public order, law enforcement, public administration, etc; a stable means of exchange of goods and services; an adequate level of demand for those goods and sevices, and a system ensuring rewards for productive effort and efficiency. These factors act essenitally on the supply of factors of production and entrepreneurship and their presence constitutes the corner stones from which the economic growth of a country begins. Their presence is assumed in a modern industrialised society, whereas many of the above are notably absent in the poorer countries.

Assuming the presence of these conditions then, an economy can grow, in a per capita sense, either by an increase in available resources per head, or by an improvement in their quality and utilisation. In other words, the flow of wealth in a country (or its output of goods and services) is created by the application of human effort, skill and ingenuity to the resources provided by nature and to the stock of capital goods provided in past times, within the framework of a particular method of organising production and exchange. It follows that economic growth requires one or more of the following: more human effort; more skill and ingenuity (including here the use of more advanced technology); the discovery of more natural resources; more capital goods (of an appropriate nature); more appropriate organization. This "formula" for growth is sometimes stated thus:

$$O = f(K.N.L.T)$$

where O is output
K is capital
N is natural resources
L is labour
and T is the contribution of skill and ingenuity and organization

2.3 CHANGING PATTERNS OF ANALYSIS

It had long been traditional for analysts of business activity and economic growth (e.g. W. Rostow) to emphasize the importance of land, labour, and capital as major determinants of economic growth. For a long time, certainly until 1914, and perhaps even until 1929, natural resources held the centre of the stage when the chances of a country's economic growth were considered. Later on, capital, a man-made and quantifiable entity, came to be considered the principal agent of growth, and if one thinks of the process of economic growth as it has been explained over the years the inescapable conclusion is that it has been thought of by economists essentially as some function of capital, namely increasing capital stocks and thereby getting richer. In the case of a poor country like India, it is still an interesting, and often appropriate, way of regarding the growth process. In a mature economy like Britain, where practically everybody is fully employed in an industrial society, this belief in the strategic importance of capital has been increasingly challenged. Among the proximate causes of economic growth today, the supply of entrepreneural and managerial abilities now occupies, in economic theory, a position of pre-eminence at least equal to that of capital. The contribution to be derived from "non conventional inputs" such as investment in people as productive agents and the introduction of improved techniques not embodied in physical capital goods is continually being stressed. In particular, since the Second World War, increasing attention has been given to the introduction of technological innovations into the economy - the principal activity of the entrepreneur-and behind this application of technical and organizational knowledge to industrial pursuits, the contribution of science and technology.

Today, the three determinants of economic progress most discussed and stressed among theorists, government, and business teachers and planners are labour, capital, and, with ever increasing emphasis, knowledge, both technological, including the results of scientific research and development, and organisational. The following quotations are conclusive evidence of this point:

"Whatever period we examine, it is clear that economic growth, occurring within the general institutional setting of a democratic, largely free enterprise society, has stemmed, and will stem, mainly from an increased labour force, more education, more capital, and the advance of knowledge, with economies of scale exercising an important, but essentially passive, re-inforcing influence." [1]

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1) Denison, E.F. The Sources of Growth in the United States and the Alternatives Before Us, Committee for Economic Development. New York.1962 p. 137

"It is no longer a question of having capital, raw materials, a strong labour force; it is now becoming an accepted fact that the basic elements of a country are its level of education and the level and capacity of its research." [1)]

"What now are the real bases of long term growth? The answer, I believe, is not capital accumulation, though this plays a necessary albeit restricted role. The answer I suggest is rather scientific research and invention. If these can be made to grow at a more rapid rate than in the past, then we shall in the usual case be able to open up deeper and broader outlets for investments, and thereby accelerate the long term growth." [2)]

"Today it is unthinkable that anyone should attempt to construct a theory of employment or a theory of growth without taking account of technical research. Within the last thirty years technical research has become a large operation that introduces fundamental changes into the operation of the economy." [3)]

"It is through technology, the humble daughter of science, that knowledge has enjoyed a revolutionary advance, especially during the last quarter century, and that it has invaded all sectors and aspects of human life. The two world wars, while causing incalculable ruin, at the same time launched upon the world the most spectacular period of technological development of all time. Today, we assess the promise of social and economic progress afforded by the systematic development and application of knowledge. Erstwhile a luxury of princes, science has become one of the most powerful instruments of human progress." [4)]

"In these days it is hardly necessary to emphasize that science is the base of modern technology, and that modern technology is in turn the base of modern economic growth. Without the emergence and development of modern science and science based technology, neither economic production, nor population could have grown at the high rates indicated for the last century to century and a half in the developed countries. Continuous technical progress, and underlying it, a series of new scientific discoveries, are the necessary conditions for the high rate of modern growth in per capita incomes, combined with a substantial rate of growth in population." [5)]

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1. Source unknown
2. Hansen A.H. Proceedings of a Conference on Research and Development and its Impact on the Economy, National Science Foundation, Washington, May 20, 1958 p.5
3. Slichter, S.H. Proceedings of a Conference on Research and Development and its Impact on the Economy, National Science Foundation, Washington, May 20, 1958. p. 2 " Technological Research as related to the Growth and Stability of the Economy"
4. Lefevre, Theo, Prime Minister of Belgium: in Ministers talk about Science, Organization for Economic Co-operation and Development, Paris, 1965 p.15.
5. Kuznets, S. Postwar Economic Growth : Four Lectures, Harvard University Press Cambridge, Massachusetts, 1964, p. 43

" Perhaps our presence here is a reflection of the conviction that the forward thrust of our dynamic economy must always get its initial and indispensable impetus from the work of our laboratories ....anyone who understands the fundamentals of modern industry knows that scientific research is the difference between profit and loss." 1)

" A unique, chronological process involving science, technology, economics, entrepreneurship, and management is the medium that translates scientific knowledge into the physical realities that are changing society. This process of technological innovation is the heart of the basic understanding which the competent manager, the effective technologist, the sound government official and the educated member of society should have in the world of tomorrow." 2)

The above quotations illustrate the remarkable interest and emphasis attached to scientific research and technology as dynamic factors influencing economic growth. In short, whether viewed from the level of the total economy or from the point of view of the individual firm, or industry, the definite and identifiable sequence of activities leading to growth is generally agreed to be : that research and development activities are concerned with the introduction and application of scientific and technical knowledge into new and improved products and processes; this activity in turn results in technological change or innovation, profits for successful companies, and increased national productivity and growth.

Of course, technological change is nothing new. It certainly reshaped the world throughout the Industrial Revolution, and it has continued as a major force in business and society ever since. However, it is only recently that constructive efforts have been made to understand and explain the process. AsDuane Evans points out:

" Technology is unmistakably a central figure in modern economic life, but each economist writes his own drama, and as we look at their various stages, we observe that, with notable exceptions, technology seems on many of them to have been left in the wings. Well into this century, for example,one might not find technological change, by name or by synonym, listed in the indexes on production economics." 3)

Until recently then, economic theory largely ignored the mechanisms of the technological and social framwork within which economic change took place. The role of

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1. An American Newsletter to <u>The New Scientist</u>, January 1964
2. Bright, J.L., <u>Research, Development and Technological Innovation</u>, R.D. Irwin, Inc., Illinois, 1964. p.1
3. Duane Evans, "<u>The Production Economics of Growth</u>," <u>American Economic Review</u>, Proceedings, Volume XLVI, May, 1956.

technology in shaping economic growth was virtually ignored by the ninteenth century economists; the classical and neoclassical economists seemed to think more in terms of rationalization than in terms of the more fundamental nature and consequences of technical change. Changes in the economic and social framework were regarded as exogenous, and their influence was eliminated from explicit consideration by the traditional assumption, familiar to students of economic theory: "ceteris paribus." When, on occasion, such changes were assumed to have taken place, they were mostly left unexplained and unrelated to the variables of economic models. It has recently been recognised, however, that these changes, which were automatically assumed away, could possibly account for a large, if not the largest, portion of economic growth. A fuller recognition of the contribution of scientific research and technological change in negating stagnation and in counteracting diminishing demand is now being granted. Classical and much subsequent economic theory, with its gloomy acceptance of stagnation, failed to appreciate this, and has now in important aspects, become obsolete. Indeed, as Enke says: "One of the paradoxes of economic history and thought is that early C19 writers feared eventual stagnation when all around them were ever more examples of the amazing ability of science and technology to multiply output."[1)]

But happily the picture has changed, and economists have increasingly felt the need to penetrate the facade of "ceteris paribus", and to investigate the mechanisms of technological and social processes in order to arrive at a more complete explanation of economic growth.

2.4 THE SHIFT IN FOCUS

What have been the causes of this rather sudden shift of emphasis in economic theory, from a virtually complete dismissal of the subject of research and development and technological change, to an almost overwhelming pre-occupation with the subject?

As pointed out earlier, technological change and innovation is nothing new; it has been going on for centuries. Yet it is only in recent years that it is receiving due attention. J.L. Bright [2)] gives at least five reasons why technological innovation or change deserves more attention today" :-

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1. Enke, S. Economics for Development, Dobson, London.1964, p. 91
2. Bright, J.L. Research, Development and Technological Innovation, R.D. Irwin, Inc., Illinois. 1964, p.1 - 2

(i) many technological advances are order-of-magnitude increases. Thus their effects and/or their inputs are significantly greater than in the past simply because of the scale of the increase in performance.

(ii) far greater man-hours, power, facilities, and funds must be applied to bring about many of these technological advances.

(iii) for the individual firms, profit, employment, and even continued existence will depend, in many cases, upon the ability of management to respond effectively to technological opportunity and threat.

(iv) new social structures and organisations are required by some advances.

(v) out of these technological advances come major social changes.

Of course technical change goes on all the time through routine product refinement, production engineering, and other technical modifications of services, products, and tools. But such advances generally represent fractional improvements over present practices; their impact is minor, and the social and economic consequences are therefore relatively easy to identify, if not to master. It is the larger and more fundamental technological advances that are today receiving increased attention.

Atomic energy, modern drugs, plastics, electronic computers, synthetic fibres - these products which have resulted directly from twentieth century science - should make us aware of the great role that invention and innovation have played in modern economic progress. Scientific research enters the picture by creating the knowledge which permits us to develop these new and improved products and processes. In fact the material record of the western world during the past century is essentially one of how novel and vastly improved ways of satisfying man's wants were discovered and adopted. The use of science in agriculture, industry and medicine made possible enormous increases in population, material standards of living, health, and the expectation of life. Any person observing these effects cannot fail to become interested in the progress of science in relation to economic and social change. Physically, natural resources are as limited as they always were. But they have come to have new uses; exploration for resources has become more effective and distant mineral, soil, and climatic assets have become economically useful through better transport. In the first place these changes are attributed to technological change, e.g. in the fields of transport, agricultural techniques, power and water, or as one writer has put it:

"I'm convinced that research and development stand squarely between our diminishing natural resources and a high standard of living. How else will we solve problems of water and food supply, control of contamination, of streams and of air? Every human need, food, shelter, clothing, health, recreation, involves critical demands for research." 1)

The economic objectives of a nation do not remain the same through time, and the general change in economic objectives in this century has tended further to concentrate the attention of economists and others on the subject of scientific research and technological change. On a national level, economic objectives in the fields of theory and of policy, have turned from prewar concern with monetary and economic stability and full employment, to economic growth. Today, in most industrialised countries a maximum increase in national income is recognised as the principal objective to be pursued; and the focus of attention is on the means available to bring about this maximum increase. In addition, within the economic structure of a country, economists and businessmen are coming to look at the competitive process in a different way. Today the focus is more on competition through new products, rather than on direct price competition, and normative conditions are shifting towards conditions of long term growth rather than fixing on short term Pareto optima - leading to what may be termed a "renaissance of Schumpeter" - and one of the factors receiving increased attention today as a factor bearing on long term growth is the use of science and technology to create new and better products and processes. This is fast becoming one of the most important economic objectives of any country. As consumers, people have an interest in higher material standards of living; as producers earning their living in a highly competitive international system, they have an interest in innovations which strengthen the country's trading position, as well as their own position within the country. On the whole, every manufacturer's goal is profits and profits depend largely on sales volume, which finally depends on the satisfaction of the wants of the consumer. In order to survive, then, the manufacturer must continually seek new ways of meeting these wants which tend to increase in range and volume as growth is experienced and incomes rise. One of these new ways receiving increasing attention is the use of science and technology.

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1. Bounty, R.H. "Automation in the Research Process," Research Management, Volume 7, No. 5, September 1964, p.23.

Of interest too in this connection is the concern with the future development of the economy . Although this concern dates back to the World Depression of the 1930's, it assumed special importance after the 1958 recession in the United States economy, which gave rise to the frequently discussed question of whether there can be a steady continuation of economic growth in the mature industrial lands. The "stagnation thesis", as propounded by the classical economists stated that the available resources of nature, labour, and capital imposed a rigid ceiling to economic growth, and once that ceiling was reached by a "mature" country, that country was doomed to stagnation. The continued growth of the economies of most Western lands which has been observed in this century has refuted the major part of these theories. Of course,it was always recognized that output must keep increasing if only because of "improvement in the arts." But this was not expected to be enough to prevent population pressure from eventually bringing economic progress to a halt. However, from the available indices of production and growth, it is obvious that something unexpected and important had occurred in the interim to refute this expectation; and that something has been regarded by many as an unprecedented rate of scientific and technical advance. During this period there was at least a threefold increase in the population of advanced lands. Their per capita incomes have also increased severalfold.

The fact of this continued economic progress is obvious; the reasons for it are not at all clear, and to obtain an answer to this question it is necessary to consider all the possibilities of economic growth. In so doing, we encounter - just as earlier growth research did - some not fully tangible interrelations which have been the subject of much of the recent economic literature. A study of eventsin the Western World during the past century have led many writers to suggest that something which might be termed "technology" may well be a fourth factor, in addition to labour, natural resources and capital, making for economic growth.

Growth historians such as Rostow have been quite emphatic about the importance of technology. For example, in his "Stages of Growth," Rostow [1)] assigns overriding importance to the adoption and diffusion of modern technology into the economy, as a prime mover in economic development.

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1. Rostow N.W. The Stages of Economic Growth, Dobson, London,1960

Of greater interest are the findings of economists in the field of what we may call "input economics." Broadly speaking, economists concerned with economic growth conceive of the total output of the economy as being the resultant of various inputs of productive services into the production process, and seek to explain the measured growth of output by reference to changes in the quantities of inputs over time.

Most of these types of study have had as their common purpose an attempt to calculate the magnitude of the residual, which is represented by the variable T in the following equation: O = f (K.N.L.T.) This growing body of research findings shows that only a small fraction of the total increase in output per worker which had occurred in the American economy since the late nineteenth century could be explained by increases in conventional inputs per worker. It is found - without substantial enlightening explanation - that in the past the real income has risen faster than the combined inputs of labour, land and capital. The lion's share of this unexplained increase in output per worker had to be attributed to something else, generally regarded as being increased productivity or efficiency. The term increased productivity covers a wide number of different elements, and the operations by which increased productivity is defined and measured obscure a variety of economic phenomena. Better allocation of factor supplies (the process of dynamic adjustment) and capital formation in human beings (for example, in the form of education and health) are two important factors, and technological change has also been considered as an extremely important third ingredient.

Solow, [1] for example, in his study of the United States economy concluded that of the total increase in the United States output per man-hour from 1909 - 1949, only 12.5% was due to an increase in capital equipment, while 87.5% was due to technological progress. He estimates the elasticities of output with respect to labour and capital at .65 and .35 respectively and the growth effect of a gradual improvement in technique as 1.5 .

Kendrick has [2] estimated that over 75% of the increase in output per man hour since 1900 in the U.S.A. was due to technical progress. Fabricant and Massel have found, in independent studies, that 90% of the rise in output per man hour is attributable to technical change. A recent study of Massel [3] suggests that between 30 - 40% of the past increase in output per worker was accounted for by capital deepening and improved resource allocation. He concludes that consequently at least 60% must be explained by technical change and improved work force quality.

1) Solow, R: "Technical Change and the Aggregate Production Function," The Review of Economics and Statistics, Volume 39, August 1957, p. 312 - 320.

2) Kendrick, J: "Productivity Trends, Capital and Labour," The Review of Economics and Statistics, Volume 38, August 1956, p. 248 - 257

3) Massel, B.F."Capital Formation and Technological Change in United States Manufacturing. The Review of Economics and Statistics, Volume XLII,May 1960,p.182 - p. 188.

Odd Aukrust has estimated from historical records of output, labour and capital for four countries, that on average, a one per cent increase in capital has been found to increase output by some 0.3%, a nineteen percent increase of the labour force has increased output by some 0.7%, and technological advance has contributed between one and two percent points to the annual growth of total output. Since the growth rate has, on average, been about 3%, this means that half of total growth has been caused by "technical improvement."[1)]

Aukrust's analysis of Norwegian growth from 1900 to 1955 has also led him to conclude that the rate of growth which can be attained in a modern industrial society is not strongly influenced by the rate of investment: that in the 1948 - 1955 period, a growth rate of 3.4% a year was made up of .46% from increased employment, 1.12% from increased capital, and 1.81% from the "human factor."

From these studies there is sufficient evidence to conclude that there are important factors of growth, besides labour and capital-hiding behind the residual T- which are loosely referred to as "technical progress," "organization" and the "human factor." The broad conclusion to the effect that the enormous increase in per capita product, which characterises modern economic growth, is largely a rise in "efficiency," that is output per unit of input, when the latter are simply man hours and material capital, has become familiar, and has been corroborated by several studies.[2)] Most of these attempts to assess the influence of changes in the principal factors of production in economic growth in mature industrial countries show that the rise in capital/labour ratios accounts for only a small part of the long term increases in output, while the traditionally exogenous variables, usually grouped together under the heading of "technical progress" account for up to approximately 90% of increases in real product per person employed.

The most comprehensive study of this kind is the one by Denison[3)] which attempts in particular to estimate the effects of changes in the quality of labour inputs associated with increased education and other changes, and to apportion the residual increase in output per unit of input among various contributing factors. Denison's figures ascribe approximately 20% of the growth of real national income from 1909 - 1929, and approximately 32% of the growth from 1929 - 1957, to the increase in output per unit of input. For the latter period, somewhat over half of the increase in output per unit of input is ascribed to Denison's residual category labelled "advance of knowledge."

1. Aukrust O. "Factors of Economic Development : A Review of Recent Research", Productivity Measurement Review, February 1965, p. 6 - 22.
2. e.g. Schmookler, J. "The Changing Efficiency of the American Economy, 1869-1938," The Review of Economics and Statistics, Volume 34, August 1952, p.214 - 231 Ambramovitz, M. "Resource and Output Trends in the U.S. since 1870", American Economic Review, Proceedings Volume XLVI, May 1956. p. 5 - 23
3. Denison, E.F. The Sources of Economic Growth in the United States and the Alternatives Before Us. Committee for Economic Development, New York.1962.

The growth of knowledge in question is the growth of all knowledge relevant to efficient production, managerial and organizational as well as technological and scientific. Denison further estimates that about one-fifth of the contribution of "advance of knowledge" to growth in the period 1929-1957 can be attributed to organized research and development; and he calculates that the social rate of return on organized research and development is about the same as that on investment in non-residual capital.

Some efforts have also been made recently to quantify the relative contribution of more than a dozen sources of growth, but it would be over-ambitious to suppose that either statistical data or techniques of analysis have yet reached the degree of refinement necessary to weigh accurately the individual contributions of the complex of factors involved. Moreover, the various factors are interdependent, the behaviour of each being both a cause and a consequence of economic growth. For example, there is some evidence of a statistical correlation among the research intensity of an industry, its rate of productivity change, and its rate of growth. But there is no evidence of a one-way relation. Hence any conclusions about the contribution of the "residual factors" must be treated with the greatest care. Calculations of the contributions of research and development, and other components of the residual, can at the moment be considered as little more than "educated guesses." For example, the calculated rate of return on research and development could be much higher if research and development yielded its contribution with a substantial lag, and furthermore, there is good cause for believing that resources are not allocated to research and development as efficiently as they could be.

However, the purpose here is not to criticise these researches into economic growth. It is generally admitted that there is as yet no practical way of accurately measuring the contribution to improved well being of technological advance. The importance of these studies to the present analysis lies in the focussing of attention on technological advance as a prime mover in economic growth, and in identifying the possible components of that mover.

There are also a few careful studies which have attempted to measure the productivity advances which have resulted from specific technological advances, and the results of these studies are quite impressive. For example, Enos'[1] study of the effects of various technological developments in catalytic cracking suggest productivity increases of several hundred per cent. Griliches' study [2] of the effects of the introduction of hybrid corn also shows very great increases in productivity. Several case histories of technology which have been written provide strong qualitative evidence of the tremendous impact upon productivity of various technological developments.

1. Enos, J. L. "Invention and Innovation in Petroleum Refining," The Rate and Direction of Inventive Activity, National Bureau of Economic Research, Princeton Univ. Press, Princeton, 1962, p. 299-322.
2. Griliches, Z. "Research Costs and Social Returns: Hybrid Corn and Related Innovations," Journal of Political Economy, Volume LXXI, August 1963, p. 331-346

But as pointed out earlier, while these examples can provide a qualitative feel for the overall contribution of technological change, it is not possible to generalize from them quantitatively. Given the present state of our economic understanding,it simply is impossible to determine the overall contribution to economic growth which technological change has played; indeed it is highly questionable to consider the contribution of advances in technological knowledge to the improved ability of the economic system to meet the material wants of society in isolation of the role of other factors.

The important role assigned to technological progress and scientific research and development in economic growth by the above research studies, has definitely been a major cause of the recent pre-occupation with these subjects. Furthermore, much valuable new work on investment in education and in training on the job has been done, particularly by Schulz, Becker and Mincer.

It has also been shown that within an industry there tends to be a correlation between the amount of research and development undertaken in a company relative to its size, and conventional signs of company health such as growth of net assets, productivity, profits and sales. This correlation is not always strong which is not surprising when one considers the many factors unrelated to research and development which can influence company growth. As mentioned, there is also doubt as to the direction of causality and consequence. However, these various studies do show that both the level of research and development expenditures and the various measures of company growth are results of something called good management. Thus it is shown that those industries that are able to exploit scientific knowledge are growing rapidly, and that an adequate expenditure on research and development at the company level is a necessary, though not sufficient condition for growth.

A brief study of the intra-industry growth pattern of the United Kingdom also provides substantial cause for regarding research and development and technological change as important elements in growth. In the present century, since 1900, there has been relative stagnation in terms of growth in mining, shipbuilding, textiles, leather, clothing, china and earthenware, and drink; moderate expansion in mechanical engineering, ferrous metal manufacture, building materials, and timber; and great expansion in electrical engineering, electrical supply, vehicles, chemicals, non-ferrous metal manufacture, glass, paper and printing, food and tobacco.[1)]

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1. Lomax K.S. "Growth and Productivity in the United Kingdom" Productivity Measurement Review, No. 38, August 1964. p. 5 - 22.

It can be seen that the stagnating trades are the 'older' industries which had enjoyed rapid growth and prosperity in the 18th and 19th centuries. Most of the rapidly expanding industries are the 'newer' trades of the 20th century owing their origination in large part to the technical change and innovation occurring in the twenty or thirty years around the turn of the century.

Furthermore, in the past decade it has been the science-based industries which have expanded most rapidly. Whereas productivity in United States manufacturing industry as a whole increased by less than 50% between 1950-60, production in chemicals, electrical engineering and aircraft and vehicles has nearly doubled.[1),2)] The effect of this trend is to be seen also in the structure of foreign trade: for example, goods with a high technological content play an increasingly important role in exports.

Other less concrete reasons have been given for the emphasis on research and development. For example, it is often pointed out that at the beginning of the century, the average labour productivity of the U.S.A. was roughly the same as that of Britain. Yet today it is 2½ times as much and rising far more rapidly. Observers of this fact suggest that it is hardly a co-incidence that research expenditure in the U.S.A. is at a much higher level. Although such statements have rather a dubious validity, on account of the multiplicity and interdependence of the various factors involved, they have served to concentrate attention on these 'new' growth factors. In this connection too, we may mention the sudden occupation on the part of economists with expenditures on education and research in an attempt to account for the relatively rapid reconstruction of a number of economies which had largely been ruined by the war, for example Germany and Japan.

R.R. Nelson [3)] also point out that "a second source of the heightened interest in inventive activity has been the cold war and the growing awareness that our national security may depend on the output of our military research and development effort - organised inventive effort for the purpose of creating more effective weapons. Closely related to the interest in military R and D (research and development) is the growing concern with the technological race to which the Soviets have challenged us."

Nelson mentions also that the establishment of the National Science Foundation (NSF) in the U.S.A. has been instrumental in focussing the attention of economists on research and development, and that the statistical series the NSF has collected and published have given social scientists much valuable background material. The Organisation for Economic Co-operation and Development in Paris is also contributing much valuable new information to the awareness of this type of problem.

1. An extract from The New Scientist, November 15, 1962.
2. Table 5 on page 31 shows the industrial distribution of research and development expenditures for several lands.
3. Nelson, R.R. "Introduction. The Background for the Conference," The Rate and Direction of Inventive Activity, op. cit. p. 4 - 5

2.5 CONCLUSIONS

"Thus when all due allowance for the concealed increase in resource expansion has been made, there will, however, remain a huge area to be explained as an increase in productivity. Our capital stock of knowledge concerning the organization and technique of production has grown at a phenomenal pace. A portion of this increase, presumably an increasing portion, is due to an investment of resources in research, education, and the like. This part we may possibly be able to attribute accurately to the input of those resources insofar as we learn to trace the connection between such investment in knowledge and its marginal social contribution, as distinct from those small parts of its value which can privately be appropriated. Beyond this, however, lies the gradual growth of applied knowledge which is, no doubt, the result of human activity, but not of that kind of activity involving costly choice which we think of as economic input. To identify the causes which explain not only the rate at which our opportunities to raise efficiency increase but also the pace at which we take advantage of those opportunities will, no doubt, remain the central problem in both the history and theory of our economic growth. The chief excuse for attempts to separate the measurable contribution of resources from those of productivity is to pose this problem as clearly as possible." [1]

That has been the purpose of this chapter - to pose the problem of economic growth, and to identify the possible causes of that growth. The problem encountered in growth studies is that the growth in output cannot be fully explained by the conventional inputs of land, labour and capital, and in economic literature there has been a change of emphasis leading away from these factors. Instead, a fourth factor of production, under the general name of "technical progress" has been identified, and credited with contributing up to three-quarters of the growth process. The probable components of this "residual" have also been identified, and it is certain that behind all these factors contributing towards technical progress, or productivity, we shall find one thing: improved human competence, and since human competence is the result of education, training, and research, the presumption is strong that these are the factors on which progress ultimately hinges:

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1. Ambramowitz, M: "Research and Output Trends in the United States since 1870," The American Economic Review Proceedings, Volume XLVI, May 1956, p. 23

"No one questions the ability of man increasingly to control his environment and produce more efficiently. Scientific discovery and economic innovation seem to be proceeding at an accelerating pace that sometimes wearies the mind although easing the body. To many people, in both advanced and backward countries, the innovation of these wonders seems to be the essence of development. Many economists are of the same opinion." [1)]

These studies have had one important result: they show that it is no longer sufficient to say that economic progress depends on increased capital, or increased labour, or both. The essence of economic growth today appears to depend ultimately on the rate at which the labour force is transferred from working with old machinery and techniques to new machinery and techniques, and to producing new and improved products, and, in the long run it is the ability of man to devise new technological possiblities, man's gradually increasing insight and cleverness alone, which influence the speed of technical progress and economic growth.

Of course, we must remember that these statistical results need to be qualified by the existence of interactions among the four sets of factors; e.g. changes in technology frequently need to be incorporated in new capital goods before becoming effective. Thus it would be erroneous to use the importance of technical change as an argument for abandoning investment activity.

Nevertheless, the results of these statistical procedures are illustrative of the major role which technical change has played; and, moreover, these results are supported by other, more direct evidence of the importance of scientific research.

Technological change, it is generally agreed, starts with invention, and there appears to be convincing evidence that science is playing an increasingly instrumental role in inventive activity: Patent statistics, research and development expenditure data, accounts of "important inventions", have all recently been used in attempts to measure the rate of invention and the level of inventive activity in various industries and sectors of the economy. The data reveal a secular shift in inventive activity away from industries based on craft and simple mechanical engineering, and towards industries based on modern chemistry and physics - in other words, towards those industries where science is important. The data also suggest the growing importance of the industrial research and development laboratory - "The modern institution harnessing science to technical progress." There appears to be a significant correlation between the amount

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1. Enke, S: Economics for Development, Dobson, London. 1964. p. 93.

of research and development work a firm does and the number of significant inventions accredited to it; and the firms which do a lot of inventing tend to grow faster, and earn greater profits.

Additional indirect evidence of the contribution of research and development is provided by studies of the returns earned by investment in research and development activity. The studies which have been done (p. 25) are admittedly of "success stories," but the figures they suggest are remarkably high. for example, the research which led to hybrid corn has yielded returns of 700% p.a.; and calculations made by some of the U.S. industrial laser laboratories also suggest rates of return to research well above profits earned from investment in plant and equipment. There are also a few studies showing that firms in an industry doing the most research and development tend to have the most rapid rate of technological change; and the industries where productivity is growing the fastest have typically been the research - intensive industries.

Consequently, from the point of view of economic analysis, research is conceived of as one form of investment of resources, the investment involving the use of human and material resources to acquire knowledge and the return resulting from the application of that knowledge to increase human welfare in one way or another. The investment approach to the use of scientific and human resources will undoubtedly contribute to the value of efforts towards higher productivity, systematic economic development of backward regions, and economic planning generally, whatever may be the political framework. On the other hand, considerations of science and education as scarce and expensive national resources will inevitably suggest problems of allocation, co-ordination and of priorities. Thankfully, the latter does not directly concern us in this study.

The former, does however. The relevant variables have been singled out and it now remains to identify them further, and, in particular to recognise, and if possible, explain, the process by which research and development activities can eventuate in economic growth.

Table 5.

ESTIMATED INDUSTRIAL DISTRIBUTION OF R & D EXPENDITURE, 1962.

(Percentages)

	UNITED STATES 1	UNITED STATES Product Field	Belgium 1961	France	Germany 1963 1	Norway 1	United Kingdom 1	CANADA Product Group	CANADA 1
Aircraft	36.3	35.3[2])	0.8	27.7)			35.4	15.7)	17.5
Vehicles	7.4	5.1)		2.6)-	19.2[5]))	2.2	3.0	1.5)	
Machinery	8.2	7.6	8.0	6.4)		5.2	7.3	5.5	4.3
Electrical Machinery	21.6	24.1	19.4	25.7)-	33.8	26.8	21.7	22.3	19.3
Instruments	3.9	2.1	..	..)		..	2.3	1.0	..
Chemicals[3]	12.6	10.4	39.6	16.8	32.9	24.4	11.6	24.4	22.3
Steel and Metal Products	2.0)	2.4	13.3	3.2	6.6	26.2	2.9)	14.2	8.5
Non-ferrous Metals	0.6)						1.2)		
Stone, Clay and Glass	1.0	0.5)	8.)	1.2	0.8	3.2	1.3)	8.	1.2
Rubber	1.1	0.7)	)		1.07	0.5	1.2)		1.2
Paper	0.6)		)	8.	0.6	4.2	0.9	5.4	6.2
Food and Drink	0.9)	5.4	2.6)		0.6	2.7	1.9)		2.4
Other Manufacturing	2.0)		13.0)		1.9	3.3	3.4)	10.0	5.7
Transport & Energy	..	5.4	3.3	9.0	0.6[6])	..	4.4)		2.7
Other non-manufacturing	1.9	..	..	2.4	2.0	1.3	1.6		8.8[4])
TOTAL	100	100	100	100	100	100	100	100	100

1. Analysis by Industry Group. Companies are classified according to the industry of their principal activity. Industrial classifications vary between countries, so this table can indicate the broad outline only.
2. Including ordnance.
3. Including petrol refining and products.
4. Including all research associations.
5. Including some steel.
6. Energy only.
7. Including wood.
8. Including other categories.

SOURCE: FREEMAN C. and YOUNG A. : The Research and Development Effort in Western Europe, North America and the Soviet Union; O E C D, Paris, 1965. p. 73.

CHAPTER 3

RESEARCH AND DEVELOPMENT

AND

THE PROCESS OF TECHNOLOGICAL INNOVATION

> "Despite the widespread attention given to problems associated with technological change, surprisingly little is known about the method by which new products and processes are invented, developed, commercialised and accepted."
>
> Edwin Mansfield [1)]

3.1 INTRODUCING TECHNOLOGICAL CHANGE

It is generally agreed that if a country enjoys an increased per capita income, or produces a greater per capita product or output, that country is experiencing economic growth. This growth is achieved either by an increase in the amount of the available resources per head, or by an improvement in their quality or utilization.

From the previous chapter we have seen that the latter has come to be known as "technical progress," "technological change" or "increases in productivity", and is regarded by many as the most important component of economic growth in recent years.

Such findings have forced a re-orientation of growth theory, and it is now generally accepted that growth models which assume "constant techniques" must of necessity be unrealistic since they abstract from what is perhaps the crux of the growth process. Instead, scholars have turned their interest to the process of technological change. The front of economic growth research at present is concentrated on two issues:

(i) to clarify the quantitative role of technological advance, or technical progress, as a promoter of growth, and

(ii) to find out what factors ultimately determine the rate of this advance.

The answer to two questions is therefore being sought:

(i) What factor or factors make up this important residual growth factor, technical progress?

(ii) How does this factor, or these factors, acting via the process of technological change, influence economic growth?

1. Mansfield, E.: "Research and Technological Change," Industrial Research, February 1964. p. 43.

At present the answer to the first question is not too clear because of the large number of variables involved, and it is a seemingly impossible task to determine the relative importance of the many factors which act to determine the advance of technology. The indications are, however, that the growth in productivity can be attributed to two broad sets of factors:

(i) the improvements in efficiency due to the elimination of various disequilibria, namely movements toward and along known production boundaries, (that is, the use of established techniques of production, and existing products).

(ii) the expansion of the boundaries themselves due to the accretion of new knowledge.

The first set of factors includes the use and diffusion of already known new or improved techniques and the elimination of various inefficiencies, including taking advantage of existing economies of scale. The second includes advances in knowledge in general, particularly scientific knowledge, inventions and discoveries, and the development of practical versions and applications of more general inventions and new scientific principles. This effect thus postulates a change in the state of the arts or sciences, namely an improvement of the available technology, and as such stresses the importance of two broadly related factors on the process of growth, namely to research, and indeed to education, being regarded as matters of national investment rather than as mere service and consuption items.

3.2 RESEARCH AND EDUCATION

There are three principal factors in a nation's economy that compete for its human resources:

1. the production of consumer goods (including the "services" industry),
2. the production of capital goods, and
3. the production of knowledge, which in turn is divided into:
   (a) basic research (the acquisition of new fundamental knowledge)
   (b) education (the dissemination of existing knowledge)
   (c) industrial research and development (the acquisition of new applied knowledge).

Broadly speaking, the advance of knowledge can contribute towards increased National Product or Income in two ways:

(i) it is possible to acquaint a larger proportion of the population with an increasing part of the knowledge acquired by man to date, thereby enabling them to be engaged in occupations that make a greater demand on their intellectual facilities; that is education is a primary requisite for economic progress.

(ii) at the same time, the absolute level of man's knowledge must be raised, i.e. research is regarded as another prerequisite for economic progress.

The transfer of knowledge through education is closely related to the creation of new knowledge by research. Both contribute to technical progress in the sense that they increase the productivity of basic factors of production. Investment in capital equipment, for example, may be regarded as one immediate cause of increased productivity. But such increase largely depends on new technology that is built into the capital equipment, a technology that frequently results from research, invention and development. These in turn spring largely from education. Furthermore, it is education in the broadest sense that creates in management and labour, and in society at large, the psychological climate indispensable to innovation and its efficient economic use.

For practical purposes then, research and education can be considered jointly as activities contributing to the advance, spread, and application of knowledge. Both involve the use of similar personnel, and research is often performed in the same institutions of higher education which produce qualified manpower for research and development activities. Education in general may be regarded as a semi-autonomous factor promoting improvements in the quality of labour; but it may also be regarded as a means of adapting the labour force to the new requirements of technology.

The importance attached to education as a factor in growth is well illustrated by the following quotations:

" To many people who have been concerned for years past about the contribution which science and scientific education have to make to the prosperity of Britain, the assertion that 'economic growth is dependent upon a high and advancing level of education' is commonplace .... from the viewpoint of economic growth, Government expenditure on education may be considered as an investment, somewhat analogous to expenditure on physical assets, which will yield a return in terms of increased efficiency and economic growth."[1)]

" To develop the gifts and skill latent in children is not merely a charitable undertaking but a rewarding investment which ensures the future of a nation." [2)]

A further example is provided in the act establishing the National Science Foundation in America, where explicit recognition is made of the inseperability of science and education:- The Bush Report quotes James Conant thus:

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1. Extract from The New Scientist of April 1963

2. O.E.C.D. Ministers Talk About Science, Paris 1965. p. 27

> ". . . . in every section of the entire area where the word science may properly be applied, the limiting factor is the human one. We shall have rapid or slow advance in this direction or that depending on the number of first class men who are engaged in the work in question. So in the last analysis the future of science in this country will be determined by our basic educational policy."

In other words, education can be regarded as a two-sided sword when considered in relation to research. In the first instance, research that increases our knowledge makes education more effective; and secondly education, if properly designed, increases the capacity for research as well as facilitating the absorption of the results of research into production.

Thus, no element of science policy is more vital than education, not only because it creates a psychological climate favourable to innovation but also because it provides the human resources without which technical progress is unthinkable. On the lower rungs of the education ladder, the need for continued change and adjustment in the numbers and skills of the labour force calls for emphasis on general education in the training of all workers, for vocational training of a general character, and for facilities for training in new techniques. In higher education, the training of future research workers and managers calls for technical training of the highest quality. With the increasing complexity of scientific and technological operations in both industry and government, more and more applied scientists and graduate engineers of the highest calibre will be required in management and decision-making positions. For education in applied science and engineering to attract talented youth, institutions of higher technical education must be of a caliber to rival the best universities.

In order to get a better grasp of the economic effects of education and research, a description is needed of the process by which research enters into "technological change" and thence into the growth process. The first step here is to consider the different ways in which scientific research can influence growth.

There are at least two good reasons for laying particular stress on research and development in growth theory. Firstly, the stock of knowledge available sets a limit on growth, particularly in countries already using the most advanced techniques. In less developed lands, there is obviously scope for economic growth within the framework of less advanced techniques, although efficient application of these to different conditions often itself requires new research and development. Secondly, since old knowledge in a form ready for extensive application is limited, a continuous and large rise in product per capita is made possible only by major additions of new technological and related knowledge.

It is also worthwhile noting that economic growth is not the only consideration underlying the need for research. In general there exist four separate and sometimes diverging needs in the field of research: [1)]

1. The spontaneous human need for knowledge.
2. The need for the solution of certain social problems, such as those related to health, nutrition, air pollution, etc.
3. The needs of national defence, and sometimes of a policy of prestige.
4. The needs related to the promotion of economic growth.

The first three needs will be briefly discussed under the broad heading of "Research in the Public Sector."

3.3 RESEARCH IN THE PUBLIC SECTOR

The advance of knowledge is of course desirable for its own sake, and the motives of individual research workers or insitutions often bear little relation to economic progress. For example, much research is undertaken for public welfare in fields such as medicine, safety, air and water pollution, conservation of natural resources, etc. without direct economic motive, although the effects of such research on growth are obvious if not measurable. Indeed it is often difficult to separate expenditures on research for economic ends from research for non-economic goals.

The public sector has in recent times assumed more and more responsibility for the creation of an adequate economic infra-structure to initiate sustain and encourage economic growth. In practice this amounts to providing a large part of what is termed "social overhead capital", for example in the form of the provision of schools, roads, communication links, and other general benefits. To provide these is a task of immense proportions requiring a sound knowledge of technology and local conditions; a task, therefore, which would be greatly facilitated if those to whom it was entrusted could be served by a team of competent and well co-ordinated research scientists. Because of the immensity of this task in developing countries it would not be surprising to find that the greatest contribution which scientific research has made to economic growth in these countries has occurred whenever scientists have devoted their attention to the technical problems associated with providing the necessary social overhead capital.

It is common to find the above research requirements discussed under the following general headings:

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1. The diagram on page 62 presents a picture of the various categories of research and their interrelationships.

1. Defence research

That is, the concern with certain areas of science derived from problems of managing efficiently those sectors of the political economy that have been established public, as contrasted with private,decision-making organizations. Examples of this type of interest are defence research, research to improve public health, weather forecasting and geographical surveys. These all have in common the fact that the goods and services involved are public goods as contrasted with private goods.

2. Research to promote the general welfare

Fundamental scientific knowledge itself can be considered a public good, for the benefits which accrue from a fundamental scientific advance often exceed those which can be traded on the free market. For example, the U.S. Government has acted to sponsor research in certain key areas such as peacetime atomic energy and space technology on the grounds that the advances which might result would be sufficiently widespread in their impact to be treated as public goods.

3. Research to serve the public interest

There are a number of industries and sectors in which, although non-research decisions are largely made by private organizations, it is felt that public interest in advancing technology surpasses the interests or capabilities of the private organizations involved. Agriculture, civil aviation, and the work of the National Bureau of Standards in the U.S.A. are examples of this interest, as are the activities of many government departments in South Africa.

The above research needs have led to government establishment and administration of research laboratories; special public agencies which contract for private research; the provision of relatively untied research funds; and various laws and institutions which can influence and aid private institutions in undertaking research.

3.4 THE APPLICATION OF SCIENTIFIC KNOWLEDGE TO ECONOMIC GROWTH

The term "Technical Progress", we have said, is often a "residual" to explain all increased output which cannot be traced to quantitative increases in inputs of labour and capital. As Domar points out [1], this "technological progress in the gross sense" consists of many influences on growth:

(i) Technical progress in the narrow sense (innovation)

(ii) Economies of scale

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1. Domar, E.D. "On the Measurement of Technological Change," Economic Journal, Volume LXXI, Number 284, December, 1961, p. 7011.

(iii) External economies

(iv) Better management

(v) Improved product mix

(vi) Labour improvements (health, education, skills).

Domar adopts this concept and gives it the name "residual", i.e. everything remaining after changes in quantity inputs of capital and labour are accounted for. As such, its contribution to economic growth is regarded as considerable.

These are all factors which according to Domar might cause shifts in the production function for the economy as a whole, or for an industry or firm. In general, and from the available studies, it is postulated that the application of the results of research and development activities leads to technological change. Clearly, the "contribution" of research to production function shifts is more relevant to certain of these factors than to others. Technical progress "in the narrow sense" has been defined to include the improvement of production processes (for example, by upgrading inputs; improvements of techniques of production or improvements of product quality) and the development of new production possibilities. The application of research results to production will effect production function shifts mainly through this first factor.

The difficulty of breaking down further the various factors of technical progress in the gross sense has in some instances caused a shift in attention to the micro-economic level. If technical progress in the narrow sense is regarded as the sum of individual innovations, these may be analysed more easily. Thus "technological progress" for the remainder of this paper will be taken to mean technological progress in the narrow sense as defined above, because it is mainly through this factor that the application of research and development results may be directly causal to economic growth.

Technological change as defined above has been credited as being the principal force behind the great changes in the economic sphere over the last century to century and a half.

> "The dominant economic discovery of the twentieth century may be stated thus: through improved technology, i.e. the application of more knowledge to a desired objective, we can generally, and not just in isolated instances, increase output in relation to all factors of input. Technology is the expression of how man obtains what he wants from nature. By continued improvements springing primarily from increased scientific knowledge of his environment, he has increased his return manyfold." 1)

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1. Evans, D: "Production Economics of Growth," The American Economic Review" Proceedings, Volume XLVI, May 1956.

Technology has been defined as "the scientific study of the practical or industrial arts" and as "truth arrived at by observation, experiment, induction." [1] As such, the state of technological knowledge limits what can be done with labour, capital and resources; what can be produced, and how it can be produced. The advance of technical knowledge, by opening new ways to meet wants and by increasing the productivity of the nation's human and material resources, has been one of the most important factors contributing to economic growth. At the same time it has also been a major source of economic disruption, often destroying the value of old skills and assets as it creates demands for new ones.

The advance of technological knowledge has increased the potential of the economic system to meet man's wants in several different ways. For example, technological knowledge has enabled a greater quantity of output to be produced from given inputs; thus the invention and adoption of the process of catalytic cracking greatly increased the amount of gasoline a given amount of labour and capital could produce from a barrel of crude oil. Sometimes technical advances have enabled the production of products better suited to certain wants; for example, nylon fibres meet a wide variety of needs better than any natural fibre; and sometimes improved technological knowledge has enabled wants to be met which could not be met at all before.

Perhaps the most dramatic impact of technological change has been in the creation of new and potentially superior ways to cater for man's needs, for example the revolutionary improvements in health care through the advance of medical knowledge and technique. The revolution in the ability to transport men and goods and to communicate would likewise have been impossible in the absence of the invention and development of the automobile, the aeroplane, and radio. In addition to expanding the range of possible goods and services, technological change has played an important role in increasing the productivity of capital and labour in the production of all types of goods.

From the above it is possible to identify several major technological trends. These have been in the fields of:

1. Transportation
2. Energy
3. Organic and inorganic life
4. Characteristics of metals
5. Sensory capabilities
6. Mechanisation - physical
7. Mechanisation - intellectual

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1. Oxford English Dictionary

It is an observed fact that conditions under the general heading of these items have undergone a major transformation in recent years; and science and technology have contributed much to producing these and innumerable other changes, so that growth in general has been characterised by a transformation of the productive system:

> "The slow and continuous increase in time of the national supply of productive means and of savings is obviously an important factor in explaining the course of economic history through the centuries, but it is completely overshadowed by the fact that development consists primarily in employing existing resources in a different way, in doing new things with them irrespective of whether those resources increase or not." 1)

Economists have always been aware of the increasing importance of new technology, but the first economist to explicitly incorporate innovation and change within economic theory and to make them the main explanation of growth and profits was Joseph Schumpeter.2)

In stressing the role of innovation brought about by entrepreneurial activity in the process of economic growth, Schumpeter states that such activity produces "spontaneous and discontinuous changes in the channel of the circular flow," which bring about "...... different employment of existing services of labour and land" which, according to him is "the essence of development."

According to Schumpeter, the impact of innovations on an economy can best be understood by considering the equilibrium that would result if there were no new products, no new ways of doing things, no new markets, no new raw materials, and no new organization for production. The economy will come to rest at an equilibrium level. The economy can grow physically without developing economically. A slow increase in population, unless accompanied by some qualitative change in the economy, exemplifies growth but does not constitute growth. Changes in the circular flow attributable to external causes - such as favourable weather conditions - may occasion short run adjustments and a temporary increase in welfare. But economic growth stems from within the system and depends on innovation (endogenous factors).

Thus according to Schumpeter, innovations prevent the attainment of stability; he asserts that new credits are introduced into the system so that innovating entrepreneurs can break into the circular flow and divert resources to new employments. Schumpeter conceived of five kinds of innovation:

1. The introduction of a new good
2. The introduction of a new method of production

1,2. Schumpeter, J.A.: The Theory of Economic Development, Harvard Economic Studies, Number XLVI. Cambridge, Massachusetts. 1934, p. 68

3. The opening of a new market
4. The conquest of a new source of supply
5. The carrying out of the new organization of any industry.

Thus the concept of innovation is a broad one, including changes that improve output-to-input ratios, increase effective demand, reduce input prices, and the realisation of latent economies of scale.

3.4.1 THE FACTORS AFFECTING INNOVATION

It is an impossible task even to identify, let alone discuss, all the various factors affecting innovation. The literature (mainly in the form of case studies) suggests many factors, both contributory and obstructive, and the most important of these are grouped below:

1. Research and development activity
2. Purchase and flow of knowledge
3. Talent
4. Economic environment and market structure
5. Investment.

It is quite apparent that none of these operates in isolation, and their interdependence provides an argument for studying several factors rather than concentrating on any one or two. However, since most of the attention recently paid to problems of technical progress and economic growth has been concerned with the contributions made by science and technology, the role of research and development activity in innovational change will constitute the focal point of this discussion.

3.4.2 RESEARCH AND DEVELOPMENT ACTIVITY AND INNOVATION

Studies on the effects of research have been handicapped by the lack of any suitable measure of outputs of research, and emphasis has been on the more easily measurable inputs. This presents real problems, since inputs do not lead directly to outputs in the form of innovation or invention; for example, much research constitutes "unproductive effort" in that it shows no concrete results. Furthermore, any form of measurement of output of research and development must suffer from the fact that there is a definite lag involved between input and output. A synopsis of the literature reveals that, broadly speaking, there have been four related types of study into the effects of research on growth which have claimed attention in recent years.

1. "Third factor" studies at a high level of aggregation.
2. Studies seeking to establish relationships between some measure of technical advance through the use of econometric methods.
3. Studies seeking to establish relationships between some measure of research output - usually patent statistics - and measures of technical advance.
4. Case studies of individual research discoveries and inventions.

In addition, there has been a fifth group of studies which attempt to bridge the gap between 2 and 3 above and which seek input-output relationships for research activities, regardless of their economic impact. For example, studies of relationships between values of inputs to research, and patent statistics. These studies essentially represent a search for a "research production function."

The "third factor studies" stem from the application of Cobb-Douglas and derivative functions to the characteristics of economic growth in several advanced countries, and a large number of economists have been engaged in this field in the recent past.[1] The main general conclusion to be drawn from these studies is that a surprisingly small percentage of the annual average growth of gross national product in the advanced economies can be explained statistically by increases in homogeneous capital and labour inputs. A "third factor" or "residual" or "technical change factor" is identified, which is assumed to account for the effect on growth of output of such factors as improvement in labour skills, health and education, improvements in the organization of production, economies of scale and improvements in the techniques of production. Unfortunately, no satisfactory technique has been found for "disaggregating" the third factor which remains in a real way, "a coefficient of ignorance." The main significance of these studies has been to draw attention to the possible economic significance of a number of factors (amongst them those influenced by education and research), which in short term economic analysis are generally taken as given. Secondly, without providing positive evidence, production function analyses leave room for the supposition that tech-

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1. e.g. Denison, E.F. The Sources of Economic Growth in the United States and the Alternatives Before Us, Committee for Economic Development, New York, 1962. Solow, R.M. "Technical Change and the Aggregate Production Function," The Review of Economics and Statistics, Volume 34, August 1957, p. 312 - 320
Kendrick, J.W.: "Productivity Trends, Capital and Labour," The Review of Economics and Statistics, Volume 38, August 1956, p. 248 - 257
Massel, B.F.: "Capital Formation and Technological Change in United States Manufacturing," The Review of Economics and Statistics, Volume XLII, May 1960. p. 182 - p. 188.
Aukrust, O: "Factors of Economic Development: a Review of Recent Research", Productivity Measurement Review, February 1965, p. 6 - 22.

-nical improvements in production processes (perhaps arising from research) make an important contribution to growth.

The second and third types of study mentioned are exemplified by attempts to correlate inputs to research in financial terms with various measurements of output. For example, research and development expenditures, suitably weighted, are plotted against rates of gross national product or against per capita gross national product; or research and development expenditures at the firm level are plotted against reductions in unit costs or improvements in labour productivity. In general, the correlations obtained are not very good, particularly when the comparisons are made at a high level of aggregation. Certain interfirm comparisons such as the one undertaken by Minasian [1] have however given more promising results, but they have not been such as to give a sufficiently general basis for setting up explanatory equations. From this point of view there are still serious difficulties to overcome, in particular the problem of determining the relevant time lags between incurring research costs and applying research results, and, for a complete specification, the problem of isolating a research production function. The main contribution of these studies to date has been to show a positive correlation between weighted measures of research and development expenditures, and for example the rate of improvement of labour productivity under certain, probably special, circumstances.

Probably the most positive evidence that there is some relationship has come from case studies of inventive activity, of individual research discoveries, and of a number of important industrial and agricultural innovations. [2] The results of these studies have in large measure been qualitative, but they have the merit that they uncover some of the over-simplifications upon which more quantitative analyses are based. The general conclusion to be drawn from these studies is limited, but nevertheless they present a useful start; they indicate that research and development has been a necessary, but not sufficient factor, in a large number of technological advances in the past. In addition, they give support to the view that research and development has played a necessary role in past economic growth in the advanced countries, thus providing empirical support for previous analysis.

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1. Minasian, J.R: "The Economics of Research and Development", The Rate and Direction of Inventive Activity, op cit. p. 93 - 141
2. e.g. Brown, W; "Innovation in the Machine Tool Industry", Quarterly Journal of Economics, 1957.
   Enos, J.L. "Invention and Innovation in the Petroleum Refining Industry," The Rate and Direction of Inventive Activity, op cit. p. 299 - 322.
   Freeman, C: "The Plastics Industry: a Comparitive Study of Research and Innovation," National Institute Economic Review, May 1962.

This method of study reverts back to Schumpeter and his theory of innovational change. The framework developed by Schumpeter has enabled modern authors to point out that innovation referred to in the sense of the introduction of a new good, the introduction of a new method of production, and the opening of a new market, is often dependent on technical invention which in turn is frequently the result of scientific research. Innovation then may be defined as "the introduction of new and improved processes and products into the economy", and is characterised by the words "change" and "production". It involves a change in the productive system as a result of the introduction of a new - or the improvement of an existing - product, process, technique or method, and is said to exist as from the time the change is actually put into operation. The term "innovation" is also applied to the introduction of such change into other firms or industries, or into other countries.

This definition of innovation differs from the traditional approach of Schumpeter, i.e. of dividing the process of technical change into the three parts: innovation, invention and imitation. Schumpeter's interpretation of innovation was both "special" and "narrow" - special in the sense of not being confined to technological production but including new marketing techniques, etc.; narrow in the sense of being a "first and only time" concept, i.e. introducing a new development. My definition of innovation agrees with his wider definition going beyond the restrictive application of innovation entailing new scientific and technological breakthroughs. I also consider, however, that innovation should be interpreted more broadly to include all related activity resulting in improvements in processes and products, and that the conventional division of invention, innovation and imitation does not emphasise the interdependent nature of all the steps of the time sequence. Innovation is a broader concept encompassing the steps leading up to, and the subsequent spread of changes throughout the national, and international, economy. However, for the purposes of this study I shall regard innovation in the rather special sense referred to above - namely, to technological innovation, entailing new scientific and technological "breakthroughs."

Regarding innovation in this manner reveals that the change has a scientific base, and we must consider the steps leading up from the scientific base to the eventual application of the knowledge in the form of an innovation. This 'cycle' of an expansion in scientific knowledge and its possible impact on economic growth has been described by Simon Kuznets[1)] in the following manner:

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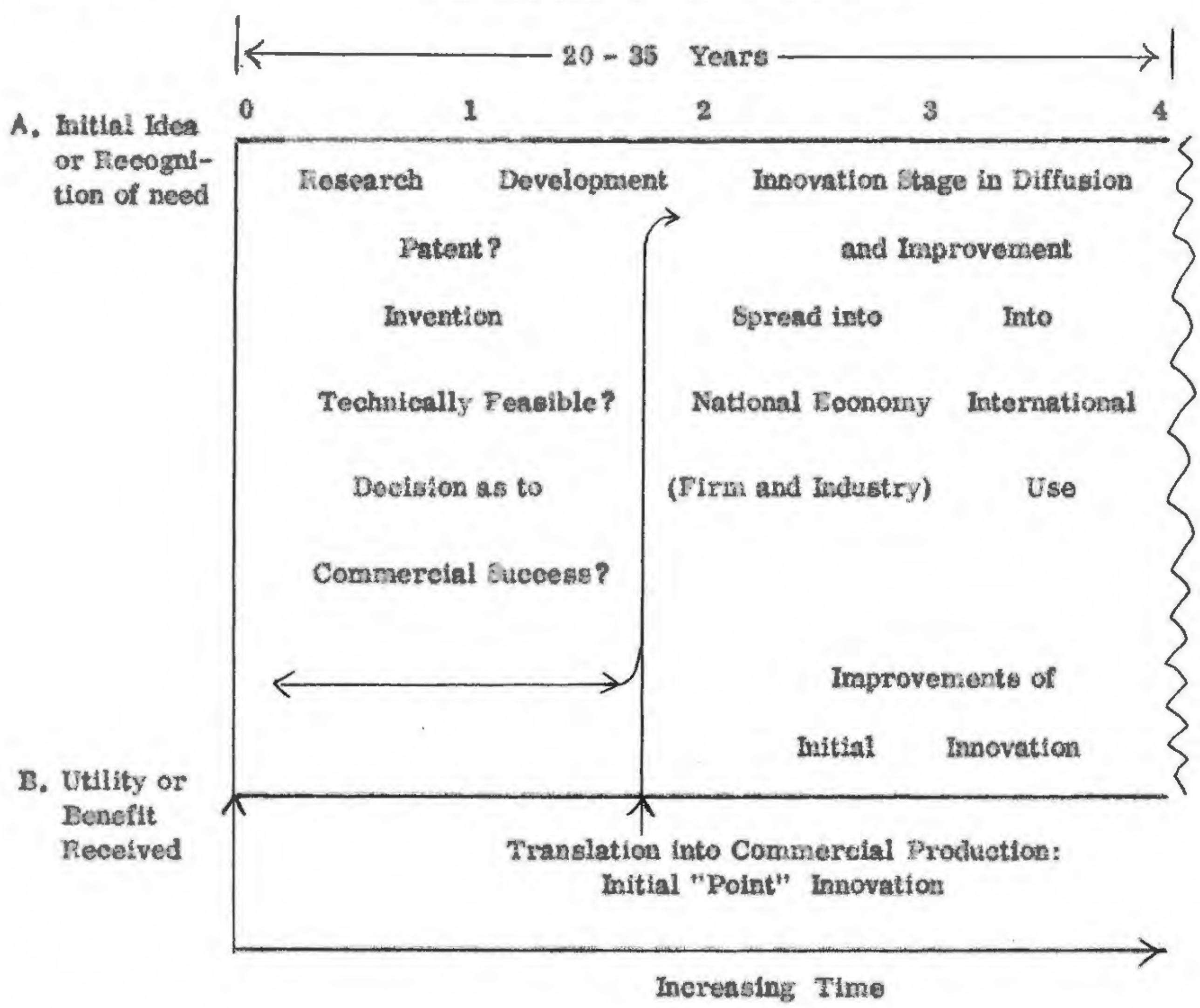
1. Kuznets, S: Six Lectures in Economic Growth, The Free Press, Chicago, 1964 p. 38

" We may distinguish the following: a scientific discovery - an addition to knowledge, ranging from a minor item like the formula for a new organic compound to a major principle like that relating matter and energy; an invention - a tested combination of already existing knowledge to a useful end; an innovation - an initial and significant application of an invention, whether technological or social, to economic production; an improvement - a minor beneficial change in a known invention or process in the course of the application; and finally the spread of an innovation, usually accompanied by improvements either through extensive imitation or internal growth. While these can be seen as successive phases - from discovery to invention to innovation to improvement to spread - there is also a feedback effect. The spread of innovations may favour further inventions, and the latter may stimulate further discovery."

It may be helpful to visualise a time sequence of the steps preceding and succeeding "initial innovation". A possible configuration is given in the following diagram reproduced from a report of the O.E.C.D. [1)]

3.4.3. THE SEQUENCE OF INNOVATION



1. Organization for Economic Co-operation and Development, The Factors Affecting Technical Innovation : Some Empirical Evidence, DAS/SPR/65.12 Paris. 5th March 1965. p. 7.

The starting point in the above flow is research and development, and this will be discussed at some length below. However, it must be emphasised that the conventional division of research, invention, innovation, and improvement does not stress the interdependent nature of all the steps in the time sequence. An attempt will be made to assess this interdependence as the various phases in the above 'cycle' receive attention.

3.4.4. THE NATURE OF RESEARCH

There are three broad categories of scientific research:

1. Research into the Physical Sciences which includes:
   - (a) the physical sciences proper (astronomy, chemistry, the earth and space sciences, physics, etc.,)
   - (b) the mathematical sciences (algebra, topology, differential geometry, analogue computing, digital computing, etc.)
   - (c) the engineering sciences (civil engineering, mining, aeronautics, chemical engineering, electrical engineering, etc.)
2. Research into the Life Sciences which includes:
   - (a) the biological sciences (anatomy, biochemistry, entomology, zoology, biophysics, botany, etc.)
   - (b) the medical or clinical sciences (internal medicine, neurology, cardiology, pschiatry, etc.)
   - (c) the agricultural sciences (agronomy proper, horticulture, forestry, fisheries, etc.)
3. Research into the Social and Human Sciences which includes:
   - (a) psychological sciences (individual psychology, social psychology, pedagogy, animal psychology, etc.)
   - (b) social sciences (history, economics, geography, anthropology, political science, sociology, etc.)

When considering scientific research as a possible causative factor in economic growth, it is usual to refer to the process of research as research and development. The dyad - research and development -refers more typically to technological creation, because it is here that the scientific findings require technological development for practical, chiefly industrial application. Science, in the form of accumulated knowledge in the natural and life sciences, provides the basis for industrialisation and further scientific research.

The extension of basic scientific knowledge, particularly when taken in conjunction with existing knowledge, allows for new applications in new products, machine tool design, materials and machining processes.

The definitions of research and development activities we shall use are those drawn up by the Organisation for Economic Co-operation and Development (OECD). [1] The manual sets out the following broad definitions of research and related activities:

1. Fundamental research, which is work undertaken primarily for the advancement of scientific knowledge without a specific practical application in view.
2. Applied research, which is defined as research work undertaken primarily for the advancement of scientific knowledge, but with a specific practical aim in view.
3. Development, which is the use of the results of fundamental (or basic), and applied research directed to the introduction of useful materials, devices, products, systems and processes, or the improvement of existing ones.

However, as the manual points out, these definitions are not sufficient in themselves, and it is necessary to amplify them by standard "conventions", which demarcate precisely the borders between research and non-research activities. Two main frontiers which require such definition are:

(a) The boundaries between research and development as a whole and several related scientific activities discussed below.
(b) The boundaries between research and development and a number of non-scientific activities of which industrial production is perhaps the most important.

It is obvious that the measurement of all scientific, and even economic, activities involves an element of arbitrariness in settling borderlines, and there will always be room for argument about the particular definition which is chosen. Thus, the demarcation of frontiers will be a matter of convention, and for the purposes of surveys of research and development activity, the O E C D manual excludes the following "research related activities" from research and development proper:

(i) Scientific information activity comprising all aspects of communication among scientists.
(ii) Training and education, including formal university education in science and engineering as well as formal scientific training.
(iii) General or broad purpose data collection.
(iv) Testing and standardization and non-routine quality testing.

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1. O.E.C.D, Proposed Standard Practice for Surveys of Research and Development, DAS/DD/62/47 (3rd Revision), Paris 1965, p. 11 - 20.

All the above activities are akin to, but seperately identifiable from, research and development, and should be excluded from a discussion of research and development proper.

In addition to the scientific activities related to research and development, there are a number of activities which draw on the services of scientific personnel but which must be excluded from research and development. These <u>non-research activities</u> include:

(i) All legal administrative work in connection with patent applications, records and litigation.

(ii) Routine testing and analysis of all kinds.

(iii) Other technical services for production units, customers, or other non-research bodies.

The guiding line to distinguish research and development activity from non-research activity is the presence or absence of an element of novelty or innovation. Insofar as the activity follows an established routine pattern, it is not research and development. Insofar as it departs from routine and breaks new ground, it qualifies as research and development. It is evident that the application of those conventions requires careful examination and judgement, and that inevitably, they are to some extent arbitrary. They do, however, provide a rational and practical basis for making the difficult distinction between research and development and "related activities".

Returning to research and development proper, we find difficulty too in the precise demarcation of the frontiers between the three phases of research, namely basic research, applied research, and development work. The generally recognised criterion for distinguishing basic and applied research is the intention underlying the research. In other words, although both basic and applied research have the common aim of uncovering new knowledge, the former is undertaken purely for the sake of that new knowledge, and not with the intention of practical application of that knowledge. Applied research, however, is undertaken with the above practical application in mind. Applied research is not to be confused with 'orientated' basic research. Basic research is said to be "<u>free</u>" if the research worker is free to choose his field, programme and method of work, and "<u>orientated</u>" if the research worker is free to choose his programme and method of work, but not his field of work. In both instances the research is directed towards the increase of knowledge without any specific practical objective.

More difficult to demarcate however is the frontier between development and production in the industrial sector. It is generally accepted that the design, development, construction and testing of prototypes and pilot plant is an essential part of research and development. The main difficulty lies in determining the point at which this development work ceases and production begins. In determining this "cut-off" point between development and production, individual judgement is bound to play some part, as no definition could possibly embrace the infinite variety of circumstances which arise in practice. The basic criterion employed by the National Science Foundation[1] provides a reasonable basis of division:

> "If the primary objective is to make further improvements on the product or process, then the work comes within the definition of research and development. If, on the other hand, the product or process is substantially "set" and the primary objective is to develope markets or to do pre-production planning, or to get the production process going smoothly, then the work is no longer research and development."

Thus, in the above context, research is taken to mean systematic intensive study to advance knowledge in all fields covered by the physical sciences, life sciences and engineering. It excludes research in the social sciences, law, education, arts and humanities, market research and the routine gathering of statistics, and it excludes all activities specified under "research related activities" and "non-research activities" as defined above.

In viewing the "inventive process" as a flow of ideas through various stages, it must be emphasised that this is not a simple unindirectional flow from one stage to the next, from inception to development to eventual adoption, but that there are usually close inter-relationships between the three factors defined above. If the output of any stage may become again an input of the same stage or even an earlier stage, one speaks nowadays of a "feedback"; several such feedbacks exist in the inventive process. For example, development includes "the engineering activity required to advance the design of a product or process to the point where it meets specific functional or economic requirements and can be turned over to manufacturing units".[2] But it is obvious that after a new product or process has been turned over to the manufacturing units, there will often still be technical problems to be solved before normal production flows smoothly. This process of "getting the bugs out" may involve some further research and development work, as a feed-back from specific problems encountered in trial production.

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1. N.S.F.: Methodology of Statistics on Research and Development, Washington, December, 1958, p. 13.
2. O.E.C.D.: Proposed Standard Practice for Surveys of Research and Development, Paris 1965. p. 14.

In addition, there is a more fundamental and intimate relationship among the knowledge producing activities. As Kuznets points out:[1)]

"We begin with the developments in science which, since the late nineteenth century, have been inceasingly the dominant source of inventions and major technological changes affecting economic production and consumption. We are witnessing a high rate of additions to scientific work and discovery, resulting in general from two factors. The first is the cumulative impact of the natural science disciplines upon each other, the higher level of attainment in physics giving impetus to chemistry, that in chemistry effecting physics, and so on down the line. There is a similar reciprocal reinforcing effect in the development of pure theory and of technical capacity for experimentation. Advances in experimental method and results, conditioned in part by the general rise in the productive powers of society, permit tests and experiments that lead to reconsideration and revision of theory, which in turn lead to new experiments demanding higher levels of technical performance. The interdisciplinary character of basic research in the natural sciences has advanced rapidly in the past few decades, and advances have been equally rapid in the relation between theoretical work and what might be called experimental and applied technology. This stimulating inter-dependence may become increasingly effective in the decades to come, accelerating the rate of addition to tested useful knowledge."

Technology in turn augments scientific knowledge. With the rise of modern science, we generally think of research and development as the promoter of current technology, but the latter continues to aid in the progress of science. Examples of technology aiding science are the microscope with its invaluable service to zoology, biology and bacteriology; and the high-speed automatic computer in the service of mathematics, physics and engineering.

3.4.5 THE RESULTS OF RESEARCH

We have said that three broad categories of knowledge-producing activities can be distinguished: pure or basic research, applied research, and development. Each of these provides knowledge inputs for the others and for itself, and the differences among them run in terms of closeness to economic use, economic versus non-economic motivation, and the degree of novelty involved. Furthermore, the institutional differences and the extent of support accorded each activity largely reflect the differing appropriability of the results.

In this connection it is useful to treat both fundamental research and the more applied forms of inventive activity as part of a spectrum of activities aimed at increasing our stock of scientific and technical knowledge. At one end of the spectrum is basic research; at the other end development and practical engineering. Moving from the

1. Kuznets, S; Capital in the American Economy, National Bureau of Economic Research, Princeton University Press, Princeton, 1961.

pure science end of the spectrum to the engineering end, the goals become more clearly defined in terms of specific practical problems; the predictability of the results tends to increase; the chances that the results will be directly of use increases, and the chances of patenting improve. We have said that technology is knowledge about the physical and life sciences as applied to practical purposes. In any given situation, several scientific and technical activities may contribute to the development of this knowledge in specific ways.

In the first instance,there may be fundamental research which seeks the principles underlying this knowledge. Such research is not directed towards a specific end product or process development but rather towards the understanding of an area of knowledge. As such, the direct output of that research is information. In fact basic research (and applied research) is motivated by the lack of information, and when that information has been obtained, the research is,by definition,completed. The result of pure of basic research then is the creation of new knowledge which, in the physical sciences, is concerned with the structural and dynamic properties of matter. It is the process of creating mathematical equations and/or experimental procedures which explain observable (man-made or nature-made) phenomena.

Applied research further crystallises the true nature of this knowledge (or other established or new knowledge) and demonstrates its potential utility through the use of bench-scale apparatus. In the American terminology, applied research is the planned search for new knowledge (whether following on basic research findings or not) which is expected to have a "practical pay-off." Applied research activities are thus directed towards building up a technological score of detailed information which will act as a base for specific product or process developments or as a base toward solving day-to-day problems within the limits of day-to-day industrial or agricultural activity. This then follows the stage of basic research and involves the application of knowledge to previously unsolved problems. It can either be product-orientated or techniques-orientated, and the key character of applied research is the uncertainty of the outcome of a proposed project. Since the problem at hand is previously unsolved, the main object is to demonstrate that the existing knowledge can be used to produce a solution.

The fact that the degree of uncertainty can vary over a wide spectrum as previously mentioned gives rise to a major difficulty in defining clear-cut separation between applied research and activities which precede and follow it. At one extreme, it is not uncommon to find applied research proposals whose outcome is so uncertain as to require in fact creation of new knowledge - basic research. We have said that uncertainty diminishes along the spectrum from basic research to development, and this has a major effect on the nature of the institutions performing the various types of research. Regarding research as a cost/investment, with uncertainty of outcome as an important factor to be considered, we find that profit incentives work a great deal better in applied research and development activities than in basic research. This has considerable bearing on the institutional framework for research as well as constituting a factor of major importance in designing effective public policy. Basic research and some applied research is generally performed in government-supported or non-profit organizations such as the universities in South Africa, and the Council for Scientific and Industrial Research. This is not always the case since many firms will maintain a basic research programme in their particular field of production for the purposes of exploiting some major breakthrough, should it occur. However, since most industrial research laboratories tend to regard research as an investment, or a "speculation in prosperity" they tend to concentrate their research activities on the latter part of the spectrum-on applied research and development activities - where the outcome of the project is more certain, and "practical payoff" can be visualised, and, if possible, forecast in quantitative terms:

> "Research is a cost/investment; far from delivering guaranteed results, it is a highly speculative, highly uncertain effort that requires the greatest managerial competence to produce results."[1)]

Confusion as to the true nature of applied research occurs most frequently at the other end of the spectrum of uncertainty where it may be confused with development. Development is the application of a known problem solution to the construction of a device or to the development of a procedure to specific performance characteristics; or it can be regarded as a technical activity concerned with the non-routine problems encountered in creating or improving industrial products or processes. The main definitional problem arises from the fact that although applied research and development activities are very similar (usually both involve the construction of a working device) their purposes are entirely different. The former is undertaken merely to show that a particular problem can be solved; the purpose of the latter is to start a chain of steps which eventually leads to offering a new/improved product to potential customers, or to the introduction of a new/improved technique into production. Development projects then are those which are directed towards a specific new or improved product

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1. Quinn, J.B.: "Transferring Research Results to Operations," Harvard Business Review, January - February 1963, p. 50

or process. A project of this nature is tangible and it results, upon successful conclusion, in a workable commercial process or product. Characteristically, these projects have:

(i) A specific end-point or result.

(ii) A time objective or target for completion - this can and should be established with a reasonable degree of accuracy.

(iii) A fairly clear pattern; although the development projects as a whole are non-repetitive, the pattern of steps - either all or in part - usually is repetitive.

(iv) Steps which are largely mechanical, as in drafting, model making, or pilot operations and testing.

(v) Comparisons with similar steps in preceding projects.

The starting point of a development project is a solution in principle; the end point is a solution in practice, or a solution in "hardware", and the requirement is to traverse the intervening distance at minimum cost and minimum time; development work thus ranges in character from improvements of an established product to highly creative applications of scientific discoveries.

3.4.6 TECHNOLOGICAL INNOVATION - THE APPLICATION OF RESEARCH

From the above analysis it can be seen that research output falls into two broad categories:

1. The direct products - information

   This includes all of the new knowledge, formulations, patent applications, operating instructions, product specifications, advice, diagnosis of difficulties, service reports, and all other information turned out in accordance with the objectives of a research and development programme. This is an intermediate step in the accomplishment of economic results through research. Two aspects of research activity make evaluation of results particularly difficult here. The first is the uncertainty of how individual projects and completed research programmes will eventuate-ranging from the question of cost and time required for a project/programme to be successful - to the question of whether it will prove successful at all. The second is the difficulty, even after a project has been "successfully" completed, of telling just how successful it has been and how much of the success is due to the efforts of the research laboratory itself. This leads on to:

2. The indirect products - economic results

   Few research and development departments have the opportunity directly to bring about economic results such as increased revenues, decreased costs, and increased profits. These ultimate results are brought about by other activities supported by the information which is provided from the laboratory. While the eventual success of economically orientated research and development thus depends to a large extent on the quality and usefulness of the research findings, it is also vitally dependent on the ability and willingness of the relevant organization to apply the knowledge supplied, and to apply it efficiently.

Thus, we are faced with a dilemma. While the direct product of research is, in the first instance, information, what we are interested in is evaluating its economic results. However, it is difficult to attribute economic results directly to research and development on a logical and equitable basis because the information is applied by other activities. Also, in some industries, research and development is just the beginning of a long sequence of activities - design, engineering, manufacturing, purchasing, quality control, market research, economic forecasting, legal studies, finance, sales and sometimes other activities - through which a project must pass before economic results are achieved. And, in most cases this process stretches out over a number of years. For example, Minasian [1] finds that the time-lag between research and development expenditures and introduction of the resulting innovation is between two to four years. Mansfield [2] notes that national diffusion often takes twenty years and seldom fewer than ten. Freeman's study of the Plastics Industry [3] shows "usually a period of five to twelve years between research and normal commercial production." This time-lag does not facilitate the evaluation of research results either.

The importance of these other activities does not mean however that research and development is a factor to be shrugged off when considering technological change and growth. Our hypothesis is that research and development is a necessary, but not sufficient factor, in certain technological changes (namely, "research based" technological innovations). We shall thus consider the steps involved in translating this necessary factor, research and development, into technological change and then raise the question as to which factors are required to make research and development both the necessary and sufficient factor for technological change and economic growth. To do this we shall have to trace the innovative process to its origins.

It must be remembered that it is always difficult, if not impossible, to follow an innovation back to a single source. An innovation is the combination of many different ac-

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1. Minasian, J.R.: "The Economics of Research and Development," The Rate and Direction of Inventive Activity. Op. Cit. p. 93-141
2. Mansfield, E: "Technical Change and the Rate of Imitation", Econometrica, Volume 29, 1961.
3. Freeman, C: "The Plastics Industry : A Comparitive Study of Research and Innovation," The National Institute Economic Review, November 1963.

tivities. Generally, on the basis of a research investigation, an invention is made and recognised, capital is obtained, plant is acquired, managers and workers are hired, markets are developed, and production and distribution take place. As the sequence of innovation proceeds, the original conception may be altered to make it more amenable to commercial realities. Some innovations - but by no means all - have their roots in scientific discoveries, and the question to be answered is how do these scientific discoveries result in innovation and growth.

Perhaps some insight can be gained into this process by looking at the functions of research claimed by overseas companies engaged in industrial research activities. These functions fall into two broad categories:

A. To protect, maintain and improve the companies' position in business.

B. To furnish the following services:-

(i) anticipate and prevent/cure troubles in production/use
(ii) reduce the cost of the product
(iii) improve the quality of existing materials/processes
(iv) abate dangers or nuisances
(v) assist in standardisation
(vi) develop new uses for existing materials/processes/devices
(vii) serve the consumer by helping to reduce costs in the use of the product
(viii) develop new materials, processes, or devices for existing or new markets
(ix) improve customer and public relations
(x) amass and distribute technical information leading to a better understanding of the product or process.

These activities all stem from the ultimate aim of the company - to make money. Research must obviously pay for itself by either cutting costs or increasing sales so as to increase profits.

In the same survey, the United States National Association of Manufacturers [1] asked the question of a group of manufacturers:

> "What in your opinion, would be the effect on your competitive position if you discontinued research activities immediately?"

The opinion was practically unanimous on the importance of research activities: e.g.

> "Impossible to discontinue research in our field."
> "Greatly reduces chances of survival"
> "Research is insurance upon our future development"

1. National Association of Manufacturers, 1962, Trends in Industrial Research and Patent Practices.

These objectivesof industrial research can be summarised under the following general heads:

(a) to preserve the profits of already existing products - "defensive" research,

(b) to increase the quality of existing earnings, and

(c) to increase earnings - "agressive research" which generally involves investment in a new product.

The research under review here, as is the case with most industrial research, consists of applied research, namely knowledge is sought with a practical application of the results thereof in view and development work. It must be remembered that a large proportion of work done in industrial research laboratories is not scientific knowledge as traditionally defined. Much of it consists of problem solving and development and design work, involving little or no effort to achieve a greater understanding of underlying scientific principles. Many of the aims listed above have a common trend - they may result in an innovation, and indeed are orientated towards that end.

The first step in the innovative process has been discussed at some length, namely research and development. Whether the scientific discovery has come about in response to a programme of basic or applied research, the result is an addition to knowledge. According to Kuznets[1], the next stage in the innovative process is invention. An invention applies scientific knowledge to the industrial objectives of physically developing (primarily) new products, techniques and processes. All scientific inquiry and progress involves a continuing accretion of knowledge, with each piece of knowledge seemingly inseperably related to prior accumulations of knowledge. In reality, we can generally identify inventions as being distinct from mere additional accumulations of scientific knowledge, because they result in something of unique importance. Thus, one definition of an important invention is based on its economic result. If a product or process resulting from a unique organization of scientific knowledge is of significant importance to a firm or industry's growth, it can be considered as being based on an important invention. Invention is thus more than a mere addition to knowledge; it involves a practical addition to knowledge and follows the applied research stage in the above mentioned sequence of events. As such, invention essentially consists in overcoming the practical difficulties of the new advance of scientific knowledge (resulting from either basic or applied research). It does not merely mean talking or writing about the new thing but involves doing it, and doing it

1. Kuznets, S.: Six Lectures on Economic Growth, The Free Press, Chicago, 1964

in such a manner that those who come after have had obstacles cleared out of their way, and have a process or appliance or product at their disposal which was not there before the inventor entered the field. Inventions are thus practical ideas, and represent a further step along the sequence of certainty. As such, invention is a process in which information is both the input and the output.

It must be emphasised that not all inventions have their roots in new scientific advances. There are a vast amount of technical possibilities inherent in the existing stock of scientific knowledge. Frequently, too, inventions arise under pressure from needs rather than from a scientific or technological base, and many represent improvements in existing processes or products instead of taking the form of radical new knowledge. For example,one writer has said of invention:

> "What is called an important invention is a perpetual accretion of little details .... an evolution, rather than a series of creations .... essentially a complex of the most diverse elements .... a new combination from the 'prior art' ..... and need not be based on 'prior science.'"[1)]

However, the case in consideration here is that of a 'science-based' invention, namely the embodiment of research findings in a practical form showing promise of commercial importance. The outcome of the research is now more certain since the idea has been reduced to practice. The next stage of the innovative process takes place when an invention, having been shown to "work" has been chosen for application. In other words the decision has been made to convert commercially feasible knowledge into commercially practicable 'hardware.' The invention is now exploited, the technical problems of adjustment being overcome by the setting up of prototypes, pilot plants and "breadboard" models.

The following step in the development of the invention is generally termed "engineering for production." The prototype may have been put together by skilled workmen using simple tools, and the entire product or process may now have to be re-designed for large scale production; specialised equipment and personnel may be needed and materials may have to be put to new uses. Generally,the launching of the product into mass production involves technical novelties that really constitute subsidiary inventions. The introduction of the new idea into the market is the final main step in the innovative process - the invention

1. Source unknown.

is converted into an innovation which, according to S. Kuznets [1] is "an initial and significant application of an invention, whether technological or social (in this instance, the former) to economic production." Innovation involves the placing of a new product on the market or the introduction of new and improved processes into production. The promise held out by the initial scientific discovery and later crystallised in an invention is now fulfilled (or negated) by the economic effects of the subsequent innovation.

Some agricultural innovations provide an excellent example of the above sequence of activities leading from research through to eventual application in the form of technological change. We may take the case of research into a new type of fertilizer in the agricultural research laboratory: if the chemical analysis conducted in the laboratory shows promise for a potentially superior fertilizer, the results of the investigation are applied (on the experimental farm, for example) to see whether the fertilizer will realize its potential under practical farming conditions. If they do, the following step involves the sending out of skilled agricultural field officers whose task is to convince the farmer of the superior attributes of the new fertilizer. If they succeed, the fertilizer will be used on the farms themselves, and the sequence of innovation will have run its course.

The above example illustrates the chain of activities described, from research through to application, subsequent development, and eventual application and technological change and, at the same time, emphasises the importance of a further factor in addition to research and development, namely the information service provided by the field representative.

Whether the eventual application of the innovation will lead to growth or increased productivity, for example in terms of increased yields per acre, will of course depend on whether the fertilizer achieves what it is claimed to do, and this will in turn depend on the efficiency of both the original research and its application to various conditions.

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1. Kuznets, S: Postwar Economic Growth : Four Lectures, Harvard University Press, Cambridge, Massachusetts, 1964.

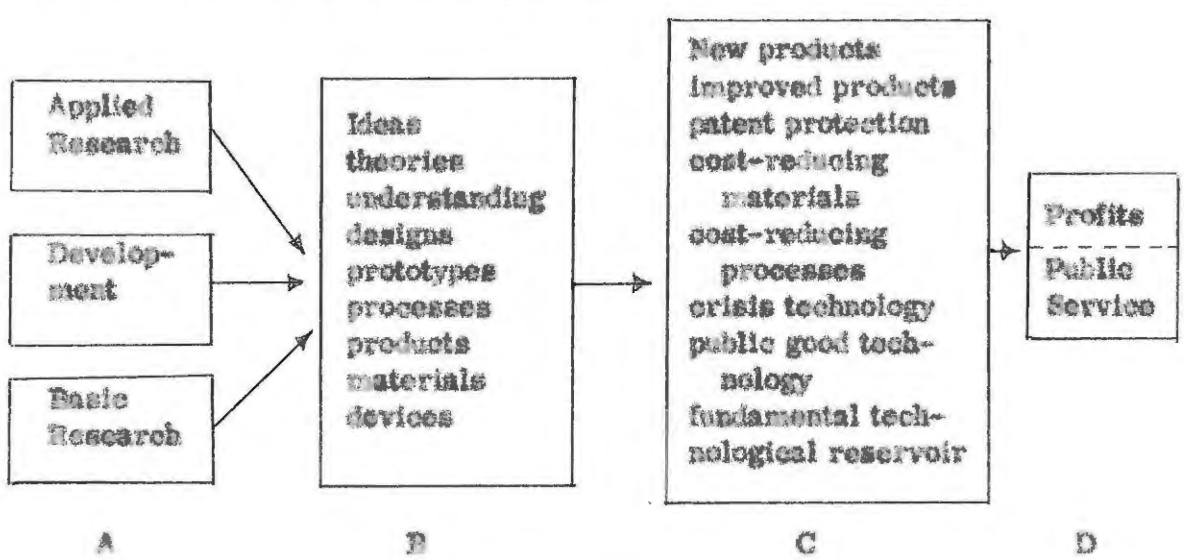
An analysis of the innovation stage in the innovative process presents new technical developments and their effect on economic growth when adopted by a firm. The concept of innovation as a consequence of scientific research, and a prerequisite of economic growth, will thus be considered at some length in the following chapter.

3.5 CONCLUSIONS

The above brief description of the innovative process has shown that the three phases of scientific research and development - basic research, applied research, and development activities - produce technology, or rather 'practical ideas.' This technology, in whatever form the research results may take, has value (economic) in that it offers opportunities for exploitation and can be exploited to support economic goals. (Whether this exploitation takes place or not will be discussed in the following chapter.)

From this viewpoint, research can be regarded as a separate and distinct activity analogous to capital investment, i.e. you invest so much money in it and get so much out of it. The uncertainty of research, and complexity of interdependent factors will, however, no doubt impose restraints on a purely investment/return approach to the research process.

J.B. Quinn [1] sets out this sequence of research to value to exploitation and its consequences in the following manner:-



1. Quinn, J.B. and Mueller, J.A.: "Transferring Research Results to Operations", Harvard Business Review, Volume 41, January-February, 1963, p. 59.

The applied scientist and engineer thus represent an essential link in the chain between the pure scientist and the final industrial product or process. The product or process developed by the scientist on a small scale in the laboratory must be handed to the chemical engineer to translate the data into a full-scale operational plant. In other words, without the technologist, the scientist cannot realise his potential, whereas, without the scientist, the technologist can do no more than improve existing processes. The scientist thus opens up opportunities for exploitation, while the technologist makes use of these opportunities - science is directed towards understanding and technology is directed towards use. A scientist is one who applies scientific method in the fundamental natural sciences while a technologist is one who engages in the scientific study of the industrial arts. As such, he is a kind of practical scientist, applying the findings of the scientist to fit the character of the industrial world and thus realising fully the potential of the research (in the box C above).

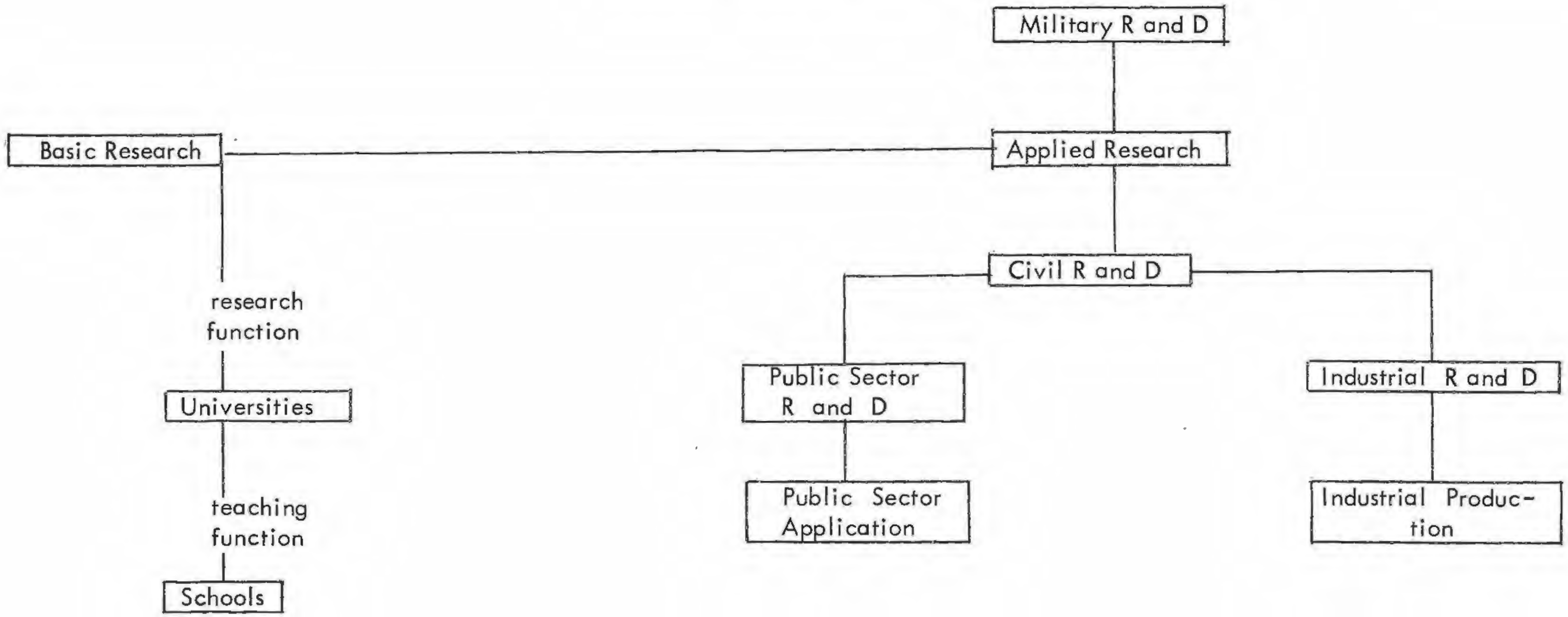
Thus for background and basic research, and much applied research, the impact on technology (represented in box C), if any, is routed through the development and engineering process. Basic research produces ideas, theories, and understanding of new scientific knowledge. These ideas and theories are consequently reduced to the more practical knowledge contained in designs, prototypes, processes, products, materials and devices, by applied research and development activities. An invention is made, and if shown to have commercial significance, is translated into an innovation; namely new products, improved products, or cost reducing materials and processes are introduced into the economy. Development and engineering activities play an important role here.

Thus, as many writers point out, recent expenditure on development is more likely to effect contemporary growth than equally recent expenditure on research. In considering the impact of research and development on growth, this might not matter if basic research, applied research, and development occurred in a fixed proportion - but they do not; the actual proportion appears to vary over time and between countries and the objectives of research and development also differ. It is not at all surprising then that scrambled totals of expenditure on research and development have not shown a significant correlation with growth in National Product in several different countries.

In conclusion, emphasis must be place on the need for information and advisory services about recent scientific advances to industry and agriculture, for we have seen that the effectiveness of research as a factor in development ultimately depends upon the application of its results.

Table 6.

GROUPING OF SCIENTIFIC ACTIVITIES.



- the world of science and its associated activities thus extend from the school desk to the factory bench.

CHAPTER 4

THE FACTORS AFFECTING INNOVATION INCLUDING THE ROLE OF GOVERNMENT

"A source of great authority over nature, the modern scientific-technology promises to be both the hope of man's future and the instrument of his enslavement or his destruction. If we are to avoid the disasters it lays open to us and take advantage of the opportunities it presents us, we must understand what modern technology is, what it means and what must be done with it if it is to serve man well."

Carl Stover[1)]

4.1 GENERAL INTRODUCTION

Research can be regarded as a business operating on ideas, and its organization is in many ways comparable with that of a business engaged in the manufacture and marketing of a product. The raw materials in the case of research are ideas - the knowledge of scientific possibilities, scientific discoveries, the technical needs of the company and so on. These ideas have to be processed in a "factory" - the research laboratory. The result of this processing is to change them into a new form and to join various ideas together to give new concepts. These new ideas then form the manufactured product and are available for exploitation. The function of exploiting them is similar to that of marketing a product and in order to ensure the effectiveness of the research, these three functions must be carried out properly. The 'effectiveness' in this sense refers to the embodiment of research in an innovation.

We have already defined the main categories of research activity, and briefly recapitulate them here. They are:

1. (Pure) basic research, or research carried out solely to increase scientific knowledge.
2. (Objective) basic research, (orientated basic research), or research carried out in fields of recognized potential technological importance.
3. Applied research, or research which has as its object the attainment of a specific goal such as a new process or product.
4. Development, which bridges the gap between research and production, and

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1. Stover, C.F., Technology and Culture R.D. Irwin Inc., Illinois 1962, p.383

includes the construction and operation of pilot plants, prototypes, etc. (A "development gap" delays or obstructs the transformation of a project from a prototype to actual production on an economic scale).

To the above we can add a fifth and most important category:

5. Application of research or technical innovation, which is the process of adopting a new or improved development in industry and of getting it to perform as it was designed to perform or better. It is this final stage alone that actually improves the productive process and therefore directly affects the rate of economic growth, although of course, without the more basic forms of research there would be few new developments to apply.

Thus, even if the total amount spent on research has been increasing at a surprisingly high rate, this does not mean that these resources have necessarily been channelled into the fields where they will have the most effect in fostering economic growth.

From the definitions above, it follows that an increase in the amount of basic and applied research that a country undertakes will not have its full effect on the productive process unless the results obtained can be applied to industry quickly and efficiently. The importance of the application of research to industry is well illustrated by the case of Japan, which is generally reputed to spend comparatively little on basic research and even less on the more basic forms of applied research; but this in no way hampers its industrial effort, since, according to B.R. Williams [1], the Japanese are extremly good at applying the results of research from their own and, more important, from other lands. The same is true of Germany.

It is this application of research results in the form of technological innovation then that is instrumental in growth. As such, the technological research has three characteristics that give it far-reaching significance. Firstly, it greatly increases the capacity of the economy to raise the demand for goods. Furthermore, technological research increases the capacity of the economy to raise productivity. Of less obvious effect, and indeed generally overlooked, is the fact that research gives the economy the capacity to bring about planned increases in the demand for goods - both by creating new demands for consumption goods and by creating new investment opportunities. Hence the term often applied to research - the "industry of discovery".

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1. Williams, B.R.: "Prosperity without Science" The Economicst, 22 June 1963, p. 1261.

It must be stressed that it is the technological innovation, embodying the research results, that directly causes growth. The research in itself is not sufficient, and as we shall see later, research is only one of several factors necessary for innovation.

4.2. INNOVATION: IT'S NATURE AND EFFECTS

At the outset, it must be noted that there are various types of technological innovation which can be identified, some of which are not based on research and development activities: e.g. routine improvements, which are minor engineering changes in which the technical knowledge for design, implementation and application are known and predictable according to Bright [1]. Other identifiable types of innovation are:-

1. Major advances, or substantial changes, in which technological direction and needs are within the "state of the art", although not previously performed (at least by the firm in question). Here the necessary technology is identifiable and seems to be achievable. Little new scientific knowledge is required although engineering development will be required to resolve the design details. In general the resulting advance will yield a major improvement in an existing device.
2. "Technical breakthroughs", which involve a radical change or improvement that requires new scientific knowledge and consequent development work, with both applied, and possibly basic research being needed.
3. "Blue-sky" projects, which are technological proposals in which the means of accomplishment or the end results are largely unknown. Substantial new scientific knowledge and consequent engineering knowledge is required, with basic research and applied research indicated.

These are only a few broad categories of innovation, since it is no simple task to rigidly define it. Bright has suggested that in examining innovations for purposes of identification, namely whether a particular advance can be legitimately regarded as an innovation or not, one looks at the "differences, increases and reductions in many parameters and effects of the innovation" and then asks the question "How much of a difference is significant?."

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1. Bright, J.L. Research, Development and Technological Innovation, R.D. Irwin Inc., Homewood, Illinois. 1964. P. 93 - 97.

He proposes a tentative hypothesis that if there is an order-of-magnitude improvement in some parameter such as speed, cost reduction, user input, etc. we probably have a potentially significant innovation. A brief review of some of the more important innovations carried out in the past suggests that if an order-of-magnitude improvement (or more) is obtained, the consequences are almost surely tremendous.

For example, there is innovation of the far-reaching type which leads to the establishment and growth of new sectors in the economy such as has happened in the industries deriving from the development of electricity, the internal combustion engine, the aeroplane and many chemical products (such as some of Du Pont's major discoveries). These have provided the initial stimulus and opportunity for growth. But innovation is not enough, and as shall be later set out, innovation must be associated with other factors to cause (rapid) output changes.

The 'parameters' of reference, or areas of consideration which assist in identifying an innovation, can be seen in the main effects attributed to 'successful' innovations by Bright [1]. These are listed below in summary form:

A. Effect on Product Performance

1. Will it (i.e. the technological change) extend the capability of the system, procedure, function?
2. Will it reduce the time, cost, space, materials or skill required to execute or achieve its performance goal?
3. Will it produce new side effects of by-products deserving attention?
4. Does it offer the opportunity for significantly different product characteristics?
5. Are there developments under way, technological or otherwise, that may eliminate the basic need for the function performed?

B. Effect on the Inputs required to produce/support the innovation.

1. Does it require new/more materials, components, energy?
2. Does it take a significantly different order of capital or have a different cost structure?
3. Does it require a change in skill on the part of the work force making the change?

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1. Bright, J.L. : Research, Development and Technological Innovation, op. cit. p. 441 - 442.

4. Does it change the productivity of labour, materials or energy used?
5. Is the supporting technological environment generally readily available - such as tools, instruments and related equipment?
6. Does it take a significantly different order of time?
7. Does it require the co-operation or co-ordination of groups?
8. Does the organization have an individual(s) with the requisite skill and determination?

C. Effect on Users

1. Does it simplify/eliminate duties and responsibilities of the user?
2. Does it change the user's costs significantly?
3. Does it provide the user with superior service?
4. Does it require individual buyers/users to alter their patterns of behaviour?
5. Does it alter the operations of institutions or affect their motives, needs or traditions.
6. Does it alter national posture or capability in a significant way?

D. Effect on Economic Society

1. Will it replace/reduce the demand for existing products or services?
2. Does it create/demand a new activity?
3. Does it require significant auxiliary and supporting activities and are they readily available?
4. What product or service demands will be increased as a primary/secondary result?
5. Will the application of this innovation on a widespread scale result in a demand for supporting technological exploration and development?
6. Does the technological base in this innovation provide potential for many new fields?
7. If the innovation is adopted, how rapidly will it spread?
8. Who will be adversely affected and how rapidly?

The above four main categories have been listed to serve three broad aims:

- to give an indication as to under what circumstances technological change can be considered as comprising a 'significant' innovation. In other words, if many of the above questions can be answered in the affirmative, then the change in question most probably qualifies for the term "significant technological innovation".

- to illustrate some of the more important economic and social effects that the introduction of an innovation brings about. This list is, of course, far from exhaustive, there being a host of minor side effects attaching to the adoption of an innovation. Some of the more important economic effects will shortly be touched upon.

. to reveal a few of the factors and conditions necessary for the successful application, adoption and imitation of innovation. These factors affecting innovation will be discussed at some length in this chapter.

To return to the second point above, it is useful to distinguish three parts of the innovative process:-

1. Invention, when, often on the basis of scientific and technical knowledge, the possibility of a new/improved product or process is concretely formulated.
2. When a firm introduces a new/improved product into the economy for the first time, that is innovation.
3. Innovation by imitation, when firms introduce products and processes which have already been introduced by other firms.

This breakdown is similar to that employed by Enos[1]. Enos arbitrarily divides technical progress into two phases:

1. The invention, its succeeding developments in both laboratory and pilot plant operations, and finally its installation or production in the first commercial plant. At the end of this phase it is in competition with the product of existing processes. Therefore, it is possible at this stage to measure its performance in economic terms.
2. Consists of improvements to the innovation by:
   a) the construction of larger units to take advantage of inherent economies of scale;
   b) the adoption of ancillary advances by another industry;
   c) the increase in operating skills or know-how.

The first phase is akin to Schumpeter's innovation for it is the innovator who carries the development of the process/product through to its first commercial application. The innovator may also continue the development into the second phase by making additional improvements; equally likely it may be imitators who recognise that the original design or operation is not necessarily the best. Technical change is thus considered to encompass imitation as well as innovation, and thereby deals with the entire process by which new technology is placed into actual practise.

1. Enos, J.L.: "Invention and Innovation in the Petroleum Refining Industry," The Rate and Direction of Inventive Activity, National Bureau of Economic Research, Princeton University Press, Princeton, 1962, p. 299 - 321.

It must be remembered that innovations are not limited in meaning to new products and new methods of making them; they also include new markets and organisations, and even new economic principles as a guide to policy. However, 'technological innovation', the subject matter of this thesis, is 'science-based' and by definition excludes the latter 'commercial innovations'. Presuming a technological innovation comprising a new or improved product/process has been successfully adopted and/or imitated, what potential economic effects will it have for the relevant firm to justify its application/imitation? We have said that there are two general reasons for conducting industrial research (the prime mover in technological innovation):

(a) to maintain/improve profits and the competitive position of the firm, which encompasses matters as increased sales, decreased costs of manufacturing new products, new processes, maintaining or improving a competitive position, or staying in business at all. (Most of these economic effects are summarised on page 66).

(b) The second main reason involves such considerations as prestige or corporate image which need not concern us here.

As regards (a), economic growth is best measured by the change in output and consumption per capita; merely adding to the numbers of producers and consumers does not necessarily change the average output and consumption per unit. Similarly, merely adding to investment facilities by extension of existing techniques is also undependable in promoting long-run economic growth in mature countries. Technical innovation and its subsequent diffusion, however, operate as a steadily renewing long-run force in stimulating investment and thereby constitute major factors in accelerating growth in an advanced country.

Improvements in production and distribution techniques comprise the keystone for economic growth as per unit requirements of men, materials and capital are reduced and these resources become available to increase the national productivity or output in other lines. In addition, new products and processes make possible accomplishments either previously not feasible at all, or not done as well. For consumers, new products acquired through research-innovation extend the range of human satisfaction and often ameliorate arduous everyday tasks by work-saving devices and consequently increase leisure time.

In the production sphere, new products and processes may result in an increased range of production and market possibilities, lowered costs and prices and enhanced profits, which together provide stoong incentives for increased investment in facilities and equipment. As innovations are introduced into the production process, resulting in more efficient use of labour and capital, long-run per capita output of the economy increases. To reiterate:
"Technological innovation is the introduction into a firm for civilian purposes, of worthwhile new or improved production processes, products or services which have been made possible by the use of scientific or technical knowledge."[1)]

The question that arises here is: "What is meant by worthwhile?" Our hypothesis is that technical innovation is worthwhile in the private sector (as opposed to the military or public sector), when its money cost to a firm is less than the resulting cost savings in the case of process innovations; or less than the additional revenues that may accrue in the case of product innovation. Worthwhile innovations make it possible to use given resources in a way that better satisfy economic and social needs.

Again,we cannot distinguish strongly enough between the effects of research (i.e. discoveries), on the one hand, and inventions and innovations. By the latter are meant the research results which have been commercialized. Technological change has resulted from the exploitation of the research results. Until this second step has been taken, the research results, however excellent they may be scientifically, are unproductive in the commercial or technological sense.

Research may, of course, be directed towards, for example the use of alternative raw materials which, either because of their lower price or greater ease of processing, offer the opportunity for making a cheaper product; or it may be directed towards improvements in the manufacturing process; or to the discovery of a new process for making the product; or to the manufacture of an entirely new product. But this is merely an intermediate phase in the growth process. It has to be exploited in the form of innovation and resultant technical change. This exploitation or application, we have said, may be effected in a number of ways and, inter alia, may lead to:

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1. O E C D, Government and Technical Innovation, Paris 1966, p. 7

- new products or the manufacture of products of higher quality and greater yields at successively lower costs.
- cost-reducing materials
- improved quality in present products
- devices for public good
- a preferred patent position or royalty income
- a material which allows the company to bridge otherwise damaging interruptions in supply.

Thus, technical change should be taken to cover changes in raw materials and other inputs, changes in the process of production, and changes in the final product itself. Here a distinction can be made between those changes which are aimed at improving efficiency of production and economy of input and those changes whose objective is to improve or change the quality or character of the final output. The former is generally referred to as a process innovation and the latter a product innovation.

To conclude this section, it is worth noting that, through innovation, a given output of production can be produced with a smaller total cost of resources. Innovation, by saving resources over-all, increases satisfaction and justifies itself. One way of saving resources is to economise simultaneously on each of the factors of production (e.g. both capital and labour) in such a way that factor proportions remain unchanged. A second way of saving resources through innovation is to substitute abundant resources for those which are scarce (e.g. labour saving innovations where labour is the scarce factor). The 'money' saved by economising on the scarce factors must more than offset the increase in cost consequent upon using more of the abundant factors. In fact it is very unlikely that invention-innovation (at least a 'signigicant' innovation) will be neutral in its effect upon factor substitution.

The above has been set out as a rather cursory review of some of the more familiar and important commercial, and to a lesser extent, social, effects of a successful innovation. More light will be thrown on these considerations in the following section.

4.3 FACTORS AND CONDITIONS AFFECTING INNOVATION

4.3.1 THE CONDITIONS FOR TECHNOLOGICAL INNOVATION

An arbitrary distinction is made between the conditions for an innovation and the factors affecting innovation:-

We shall regard the former as prior in time, and practically a requisite to, the latter. Thus by conditions for innovation are meant those conditions that must be present to make the firm aware of the need or profitability to innovate. Once the decision to innovate has been made (the conditions being fulfilled), various factors are necessary, either singly or in combination, to justify this decision variable of the firm, or in other words, to bring about a successful innovation. As can be seen from what follows, this distinction is sometimes rather difficult to draw because of the interrelationships between the various factors.

There is a strong need for managers to identify potential technological advances that will have economic value in wide-spread use, within a time significant to the firm. There are certain necessary conditions to achieving this value. In summary, the concept must eventually prove to be:

1. technically feasible,
2. economically feasible,
3. of economic interest to the user society. The criteria under this head are:
   - better than the status quo,
   - better than any technological competitor,
   - nothing in sight to invalidate its fundamental purpose,
   - significant volume will be available
   - the cost does not exceed the user's needs, and
4. timely. This implies timeliness with respect to need, to the availability of necessary supporting services, and to acceptance by the potential users.

In more detail, the first condition generally agreed upon as bringing innovation into being is the existence of some incentive for, or pressure on, the firm to do so. The need to innovate may be felt for many different reasons, e.g. the pressure of innovation by competitors; shortage, or imperfect quality, of materials; the insistent demand that people should have a higher standard of living, etc.

In this context, Professor Williams[1)] examines two diverging theories:

1. Williams, B.R.: "Competition and Efficiency" Applied Economic Papers Osmania University. India. September 1962. p. 143.

(i) innovation decisions resulting from a reaction to the competitive pressure of numbers and to falling profits (this is the theory upheld by Marx, Lange, Downie).

(ii) innovation decisions in firms enjoying a protected position (e.g. as put forward by Schumpeter and Galbraith) Williams, however, rejects both these theories as outright solutions and denies the existence of any optimum condition favourable to innovation. Instead, he considers that both pressure and opportunity are necessary conditions for innovation, but are not sufficient factors in themselves.

Williams and Pavitt [1] suggest the following:-

(i) a firm is confronted with pressures to innovate which may be external - from the competitive force, customer demands, and suppliers of materials and equipment; or internal - from the personnel of the firm or from intra - firm rivalries. In connection with pressures, it is interesting to note that an innovation can be "exogenous" in the sense that it came into being independent of factor prices. But many innovations are induced by factor price changes. They are the result of entrepreneurs seeking to introduce entirely new methods that increase the productivity of those factors that are becoming more expensive. Even if inventions offered by scientists are "neutral" as between labour and capital, the innovations of producers may be induced for they tend to exploit only those inventions that offer a way of escaping the higher priced factor.

(ii) a firm must have the opportunity for innovation, and most important, be aware of this. In other words, the firm should be able to identify technical and commercial opportunities for innovation.

Opportunities may be technical, viz. opportunities involving the potential to apply units to the productive process; or commercial, viz. the opportunity to provide a product for a new customer or to meet investment demand for example. The potential in itself is not sufficient condition; there must be a recognition or awareness of it.

Technical opportunities, therefore, can (but do not necessarily) result from research and development work undertaken within the firm and also from suppliers of equipment and raw materials; from the innovations of other

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1. Pavitt, K.: "Research, Innovation and Economic Growth," Nature London, October 1963.

firms which can be purchased under licence; from institutes of co-operative and sponsored research; from technical information and advisory services, and from individual inventors. This approach once more focuses on research and development as an investment in progress - an investment in the creation of opportunities for further investment. In other words, technical opportunities can be regarded as technical opportunities to invest and involve the existence, in a suitably developed form, of processes and products which could be adopted by a manufacturer. The "nursery grounds" of technical opportunities for investment are the research and development departments of the firm itself; the sales departments of supplying firms; the buying departments of customer firms, or occasionally institutions (like some research associations) conduct applied research to the point of commercial significance or usefulness; or which, like the National Development Research Council of Britain, introduce discoveries made by government bodies to a wide circle of users.

Commercial opportunities are most often inherent in changing patterns of demand for goods and services, and from the opening up of new markets.

(iii) The firm must also have the capacity to innovate. The capacity to innovate is chiefly a matter of resources such as ability and talent; availability of investment funds; size to carry through an innovation and to profit from it, etc. Primarily, the firm must have at its disposal:

(a) the managerial and technical capability to choose the opportunities for those innovations most likely to be profitable, and to effectively manage its own research programme, and

(b) the financial capacity for the research-innovation, investment and marketing activities that the innovation may require. Thus,as a whole, and as shall be expanded upon in a later section, the speed and effectiveness of technological innovation in a country depends primarily on the competence and initiative of private firms.

(iv) (a) The flow of knowledge from an existing and created stock into the production process.

(b) The pressures and opportunities above and below the innovating firm, e.g. ideas or demands passed on to a firm from other individuals or firms during the time sequence in which the innovation occurs.

There are also some studies showing that external characteristics of opportunity and pressure derive from outside origins of innovation. For example,

(a) a study by Freeman [1)] points out the high innovation density of the capital goods industry and the effect of this spreading innovation throughout the economy .

(b) Peck [2)] finds that inventions originate where profits will result most immediately, and that, in the aluminium industry, this comes:-

  (i) for product innovations in the primary producer sector, and

  (ii) for process inventions in equipment-makers rather than end-product users or primary producers.

(c) A study by A.D. Little Inc. [3)] finds that innovation in "mature" industries usually comes from outside, due to the inertia and narrow commitments of traditional industries. In this approach, technology flows in three different ways from new industry into old:

  (i) the mature industry buys/borrows technology from the new.

  (ii) the new industry invades the field of the old.

  (iii) the product of the new industry replaces that of the old.

(d) W. Mueller [4)] shows that of 25 important product and process innovations applied by Du Pont, only 10 were based on inventions made by du Pont personnel.

The above conditions must be fulfilled in large part before the entrepreneur undertakes the decision to innovate. A synopsis of these conditions reveals four closely related and mutually reinforcing broad factors: knowledge and technical information (including communication), talent (managerial, technical and general labour training and education), environmental factors such as firm size, public attitudes, market structures, etc, and, lastly, investment. The innovating businessman makes his decision on the basis of these factors

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1. Freeman, C: "Research and Development : A Comparison between British and American Industry." National Institute Economic Review, May 1962.
2. Peck, M.J. "Inventions in the Post War American Aluminium Industry," The Rate and Direction of Inventive Activity, op. cit. p. 279 - 298
3. Little, A.D. Inc: Patterns and Problems of Technical Innovation in American Industry, NSF, Washington PB181573. 1961
4. Mueller, W.F.: "The Origins of the Basic Inventions Underlying du Pont's Main Product and Process Innovations," The Rate and Direction of Inventive Activity, op cit. p. 323 -358.

being present. What the effect of an error in his estimate of the capability of his firm to innovate successfully on the basis of these conditions will be, is illustrated in the following section, where the main factors affecting the success of innovation are discussed.

In Chapter 3, these various factors affecting innovation were listed under the following five general headings:

1. Research and development activity,
2. Purchase and flow of knowledge,
3. Talent,
4. Investment,
5. Economic environment and market structure.

Research and development, of course, will only influence innovation in the rather special sense of technological or science based innovation which forms the subject matter of this thesis. As such, research and development has been discussed rather extensively in the previous chapter, and will not directly concern us here. It must be noted, however, that research and development enters indirectly into all the other factors about to be discussed since it is the results of research that form the essentials of the innovation. Thus one cannot consider factors affecting the latter without touching on the former. Furthermore, these other factors may have both a positive, or negative effect (e.g. the purchase of knowledge can be regarded as a negative factor affecting innovation as far as indigenous research and development is concerned.)

A proper understanding of modern technological change must involve consideration of the various factors bearing upon technical innovation. The primary factor, namely research and development (since we are dealing with <u>technical</u> innovation), its nature, causes and results, has been discussed. Now we must consider the other factors necessary for the incorporation of the results of research and development activity, in the form of innovation, into the economic structure. In other words, the mere existence of change is not enough in itself. We must consider also the pace of change which is dependent not only on the innovation but also on the adaptability of the economic, social and cultural structure or environment into which it is introduced.

The absence of one or more of these factors may present serious obstacles to growth. Simon Kuznets[1], for example, says that there exists a bottleneck relationship between the successive phases of the innovational process. For instance, at the link where innovations transform new technological knowledge into production reality, he stresses that there are three important and obvious factors;

(a) Many major inventions, if they are to become successful innovation, (in terms of increased output, reduced costs, etc.) demand heavy capital investment, both in material goods and in the training of the labour force.

(b) Innovations represent something new and require entrepreneurial talents and skills to overcome a series of unexpected obstacles.

(c) Much depends on the responsiveness of the would-be users of the new products/processes for their adoption to widespread use and hence mass production.

According to Kuznets, all the requirements combine with the necessary condition of increased technical knowledge to present the sufficient condition for modern economic growth. Let us first look at this "necessary" condition for economic growth.

4.3.2. THE FACTORS AFFECTING INNOVATION

A. The purchase and flow of new knowledge

One cause of increased technical knowledge is research and development conducted by the firm itself. However, a further input of knowledge, in addition to research and development, is the purchase of know-how and expertise from outside. This, on a micro-economic scale, a firm or industry can provide the necessary condition for growth without undertaking actual research and development work. Of course, this is not to say that the research and development as such is redundant - it is highly probable that the new technical knowledge has resulted from research and development in another firm or sector of the economy.

On a national, or macro-economic scale, the purchase of knowledge is apparent in the growing trade in technological know-how, partly reflected in the purchase of patents and licences. This trade is shown in National Income figures as the

1. Kuznets, S: Six Lectures in Economic Growth; The Free Press, Chicago, 1964

"Technological Balance of Payments",[1] and is also reflected in the exchange of technical and scientific documentation and patent flows between countries.[1] It is hardly surprising that the most technically advanced economy, that of North America, has a considerable balance to its credit, and that other countries show a deficit, the degree of "dependence" roughly approximating their technical ranking. Again,this is not unusual when one considers the American lead in the volume of research and development activity.

These considerations are often ommitted when comparing the ratios - research to gross national product - of various countries. For example, Canada has a ratio of less than one per cent although her per capita national product is higher than most Western European countries. It should be remembered, however, that a very large part of Canadian industry is foreign-owned (particularly by technically advanced American companies), and to some extent the results of United States, and other, research and development activities are transferred to Canadian subsidiaries by parent companies, although they may not be performed in Canada. Japan and Germany too, are good examples of flourishing economies that have by this manner, managed to circumvent to a large extent the need to invest in research and development facilities. In South Africa too, the inflow of newtechnical knowledge from abroad has been of primary importance. Some 200 agreements to licence foreign know-how are signed every year, and the industries most concerned - engineering, chemicals, clothing, building and transport - have all grown rapidly. Know-how also flows in from overseas companies to their local associates and subsidiaries. There are even the beginnings of a reverse flow of South African techniques back to overseas patents.

These international figures, even if broken down by industries, show only part of the picture since there doubtless exists a large internal trade in payments and licences between the more and less technologically advanced firms. Furthermore, there are also differences in the technological balance of payments of the various industries within the countries. In any event, payments for patents and licences reflect only a (minor?) portion of the flow of knowledge, for much know-

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1. Refer table 7 (p. 114), table 8 (p. 115) and table 9 (p. 116).

ledge travels embodied in personnel, as consultants, or by means of transfers; as mentioned, much goes undetected from parent to subsidiary firms, and perhaps even more through the sale or loan of capital equipment in which new technical knowledge is embodied. The importance of technological aid to underdeveloped and developing countries is illustrated in the aid programmes of the West and Russia, in particular in the form of trained technicians, modern capital equipment, etc.

A note of warning must be sounded here. The adoption of another nation's production practices and their application to local conditions is often quicker, cheaper and easier than the development of new knowledge, and more often than not,equally profitable. None the less, it often requires a large effort and extensive use of resources (and often competitive pressure)to adapt these practices to local requirements. Among other things, it probably requires much the same kind of technical and managerial talent as does new research. For this reason, it is quite likely that, by facilitating the adoption of known techniques, and by expanding the number of engineers, scientists, and well-educated management personnel, technological change can contribute more to growth in Europe than it can in the United States. This is particularly relevant, if we remember that the more mature a country is, the less it can take over the advanced technology of other lands, and the more it needs new investment in research, for example,to stop a fall in the rate of growth in per capita output.

The interchange and adoption of other known techniques means that the science-based industries are beginning to have a strbng influence on the degree of innovation in industries based on traditional techniques of production. Furthermore, 'international commerce' in techniques of production, through the purchase and sale of manufacturing licences, is most developed between the industrially advanced countries in the science-based industries. Thus a country, industry, or firm can, to some extent (often a considerable extent), substitute the buying of manufacturing licences for its own research and development efforts. However, since the assimilation and improvement of sophisticated techniques from abroad requires some working knowledge, and since no advanced country, industry of firm can afford to assimilate all its techniques abroad, the industrially advanced countries need to develope their own research and development capacity. This point cannot be stressed too strongly, especially in the national context. The efficient development of resources demands from the first a continuous production of scientific knowledge regarding their specific properties and potentialities. Every aspect of national development policy depends on research conducted within the country, although it must be based on the achievements of, and conform to, international science. A national research potential must be developed to carry out effectively any other national policy and to neglect a planned and vigorous development of indigenous research in the physical, biological, life, and social sciences endangers the whole process of development.

Thus in South Africa, although the importance of the inflow of technical know-how was acknowledged, it was recognized at an early stage in the country's development that the restrictive conditions under which knowledge was sometimes supplied to South African firms could prove harmful when a drive to export manufactures on a large scale was embarked upon. The increasing appreciation of the importance of indigenous technological knowledge in South African economic growth has, since the war, led to a considerable increase in research activity, both basic and applied, as evidenced by the foundation of the Council for Scientific and Industrial Research and other research institutions.

Bearing this important limitation in mind, and granted that the purchase of new knowledge is of primary importance for innovational change and growth, what positive steps are necessary to ensure the successful operation of the factor?

On the one hand, in the drive for greater productive efficiency, industry must be encouraged to utilize every piece of scientific knowledge available. What is required is not simply research and development but a more intensive application of existing scientific knowledge, whether already in existence in the firm, industry or country, or available from outside. The productivity of research depends strongly on one's ability to profit from what is being or has been done by others, and this requires constant and comprehensive attention to the technical literature with complete coverage of the subjects important to the investigator, the team, the firm, industry or country itself. The development of the communication and information flow into and within a firm, industry or country contributes to the awareness of available knowledge and its effective use.

Thus the question to be answered is whether actual research and development is needed or whether an institution for spreading scientific and technical information can lay the necessary foundations for technical change, and there is a clear need for information and advisory services to industry and agriculture. This importance is well illustrated in the following quotation on the activities of the D S I R in Britain: 1)

"The central part of D S I R's problem is the need to convey the results of research in a form which points the way to its practical application."

In fact, the Advisory Council on Science Policy in Britain, in its review of the balance of scientific effort in resources and manpower in the non-military field concluded, inter alia, that a great deal could be achieved relatively quickly and economically by the application of existing knowledge, particularly in the case of development of new products and processes in industry It noted further that the problem of technical information had been a serious handicap in closing the development gap, and identified two distinct problems in this connection. The first was the problem of conveying technical information to small firms and industries which lack the resources to keep abreast of the flow of technical literature, and the second was the problem arising out of the enormous growth of output in scientific literature in all countries, which exceeds by far the capacity of the individual, even in his own special field to deal with. The C S I R in South Africa is faced with a similar problem, although it has already achieved much in this sphere.

In the long term then, it would appear that greater adaptability can only be achieved through the expansion of technical education and, in the short term, initiative (chiefly governmental) is required to achieve a significant improvement in the dissemination of relevant technical information to scientifically backward firms.

In conclusion then, it is clear that technical change or innovation may take place without new knowledge resulting from own research and development

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1. D S I R, Management and Control of Research and Development. HMSO London, 1961. Par. 160.

activities. In some instances, research and development may not be needed at all, for example by the modification of existing products, or from direct installation of already existing techniques. Even where new knowledge is required, it may already be available from outside and it is possible that information and advisory services will meet the basic needs. An important qualification is that,even if there are techniques in existence which might be suitable, research may be needed, nevertheless, in order to adapt them to local requirements. One of the main problems in technically backward industries is to get the entrepreneur to make use of existing knowledge and to use the large number of possible technical improvements which are already known. So that what is mainly needed in such cases is information and subsequent applied research, probably in the form of research to adapt existing technical knowledge to specific conditions.

Thus we have seen that there are different means of acquiring the new technical knowledge essential to innovation, whether they be derived from the research and development activity of the firm itself, or from the activities of others. However, the technical knowledge input by itself will nearly always be insufficient to achieve technological innovation; for one thing there must be available in the innovating firm the required suitable personnel.

B. Talent-level and distribution

"At many points in the economy and the social system it is the supply of first rate ability which determines the speed of change." 1)

The process of innovation is affected by the level of talent at all stages of the time sequence and a high level of talent is essential to the acquisition and application of knowledge. This factor can be viewed in three broad perspectives:

(1) the supply of scientific and engineering personnel,
(2) their location and place in the firm,
(3) the general education and attitude of labour and management.

1. Carter, C.F. and Williams, B.R.: Science in Industry, Oxford University Press, London,1961. p. 95.

(1) The supply of scientific and engineering personnel

The supply of scientific and engineering personnel varies greatly among countries, and among industries of the same country: For example, in Table 10 p. 117, it can be seen that the USA and Russia have proportionately more qualified scientists and engineers (QSES) than do most other countries.

Regarding differences between industries, a Federation of British Industry's (FBI)[1] Study found that the research ratio of qualified scientists and engineers per 100 of total employed was approximately 1.0 for aircraft, fibres, chemicals, and electrical engineering; 0.1 for printing, cotton, wool, hosiery, wood and furniture, drink, leather and clothing. Technological innovation is a technical activity and its successful application (and origin) requires the services of technical people, or scientists, engineers and technicians. Indeed, as Carter[2] points out, it is significant that the speed at which individual firms apply technological innovations will depend, in most firms, on the number of qualified scientists and engineers employed and, from the FBI survey mentioned above, there appears to be a direct correlation between the size of the firm and the number of scientists and engineers as a proportion of its labour force.

"We must remember that the first requirement for high productivity in research, the production of new ideas, novel techniques, new materials and processes and the exploitation of these is to ensure that manpower of top quality is selected and trained in suitable ways. This is especially important in the United Kingdom where the supply of manpower of the requisite quality is strictly limited - not always by lack of money and facilities, but by sheer ability."[3]

To gain some measure of the importance of this factor for technical innovation, let us repeat ourselves briefly. The big contribution of science and technological change in the last century or so has been in the substitution for man-power, of power derived from coal, petroleum, hydro-electric schemes, etc., in the manufacture and production of the necessities of life and in providing means of transport and communication. This has placed a premium upon the services

1. F B I Survey, Industrial Research in Manufacturing Industry, London 1961, Table 3,p. 67
2. Carter, C.F. and Williams, B.R.: Science in Industry, op cit. p. 12
3. Sir Harry Melville: Proceedings of the Symposiom on Productivity in Research. London 11 - 12 Dec. 1963, p. 2.

of engineers for the design and construction of more and more machines and upon the work of scientists for the provision of increased knowledge upon which the construction of new and improved machines can be based. It also places a premium upon the services of technicians to support scientists and more particularly, engineers in the design, planning, control, maintenance and operation of machines and devices. This has meant the passing away of the older notion of the skilled craftsman of earlier times as a unit of production. The "Second Industrial Revolution" or "Technological Revolution" has called forth a far different brand of skilled worker.

Questions such as these raise the urgency of a properly formulated educational policy to cater for the changing needs of society, and, to borrow from the Organisation for Economic Co-operation and Development, [1] mean that:

"Issues of education planning are inextricably involved in any consideration of science and policy. This link is intimate and progressive. It extends beyond the problems of science education alone. That scientific education might be seen and separated from education in general is indeed one of the dangers of the increasing demand for trained scientific personnel. The proper balance between technical and other forms of education is one of the major problems of policy that must concern economist and educator alike."

Russia was the first under-developed country to deliberately plan for the new technological era. The basis of Russian planning was the widening of the school curricula so as to ensure that all school pupils have an excellent introduction into the sciences before they leave high school. Furthermore, a large proportion of the pupils go on to some form of advanced education in science and technology.

In this respect, there is a rapidly increasing gap between a typically highly industrialized area on the one hand and an under-developed area on the other. This kind of gap exists in a much smaller context between the different racial groups within South Africa and the difference which already exists between the

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1. O.E.C.D.: Ministers Talk about Science, Paris, 1966, p. 96

Bantu Homelands and industrial South Africa is regarded by many as an underlying cause of much of the economic stresses which beset our country.[1] The position in South Africa is particularly critical when one considers that a community of roughly 15.8 million people is still dependent for its scientific and technical skills upon the small European population of little over 3.0 million.[2]

In the highly industrialized countries of the West, a conscious appreciation of the educational problems involved has led to positive action in recent decades, such as the reform and extension of the higher education sector including the growth and establishment of colleges of advanced technology, and technical colleges in the United Kingdom. In South Africa, great strides have been made in the direction, but they are still insufficient, and indeed will remain so as long as science teaching remains a relatively low paid avenue of employment for South African scientists and for as long as we have to rely on a relatively small European population to provide scientists and engineers to man expanding industries. Education and training in science and technology in South Africa, whilst far in advance of that in other African countries does not appear in too favourable a light when judged by standards in industrialized Western countries. And, if the standard which we wish to maintain in the future is to prove comparable to that of industrialized Western communities, then our sights must be set at what is being done in such communities, and not by comparison with what is being done in the less developed countries of Africa.

Our future industrial and economic health is thus very dependent, in the short term, on the selection and training of the maximum number of scientists and technologists from our limited white population. In the longer term, it is dependent upon the rate at which the non-white peoples can be educated and trained.

(2) The Location of scientific personnel in the firm

Not only is the number of technical or scientific personnel important but also their location. We may ask whether it is better to have a greater percentage of scientists and engineers engaged in research or in production, design, sales and administrative posts. The distribution of qualified scientists and engineers

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1. For example, D.H. Houghton Men of Two Worlds: Some aspects of Migratory Labour in South Africa, Presidential Address to the Economic Society of South Africa, 1960.
2. Rapson, W.S. Science and Technology, Witwatersrand University Press, 1963

in the different industries varies widely according to the country, e.g. in the United States, qualified research scientists are heavily concentrated in the aircraft, electronics, instruments, electricity, and chemical industries.

The question of the location of personnel within a firm and their distribution between research and development and other activities merits closer attention. B.R. Williams [1] points out that "Scientific manpower is something we are short of, and even more importantly, something which has alternative uses. The more of this manpower that we use in research and development, the less there is available for use in production and related activities. I have no doubt at all that the Germans use a higher percentage of their scientific manpower in production and related activities. They are in fact, because of this, in a rather better position to exploit scientific and technical knowledge from wherever it comes than we are ..... In other words, if you are looking at this tremendously important natural reserve of scientific manpower you can see that it is possible to have too much research, looked at from the standpoint of economic growth. It is possible to bring about a state where you fail to use a great deal of scientific and technological knowledge because you are not employing enough of the people capable of using it in the right place."

This viewpoint is highly significant today as evidenced in the growing demand for the services of scientific and technical personnel. It is an empirical fact that scientists and technologists (including engineers and technicians) are not only used in research and development work. Technological innovation depends not only on research and development, but also on the capacity of firms to use its results; this capacity, in turn, being partly dependent on the proportion of scientists and engineers employed outside research and development, in production, marketing, and general management. The proportion of the stock of scientists and engineers which can profitably be devoted to research and development activity is, therefore, likely to be partly a function of the absolute size of this stock. Furthermore, given this sort of variation, it is clear that the appropriate distribution of scientific manpower varies with the industrial structure; but unless the distribution is appropriate, the full growth potential will not be realised.

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1. Williams, B.R. In note of address given to the Parliamentary and Scientific Committee, London 21.7.64 p. 2.

This aspect of the appropriate distribution of manpower stresses the importance of communication between the various divisions. To improve the productivity of industrial research in general, it is essential that it should not be an isolated activity. There must be constant interchange of ideas with production and marketing,and continued planning and vetting by people aware of these other aspects of business. Research staff themselves must be trained to be commercially and technologically versatile. This ties up closely with the information needs discussed under the previous section on knowledge.

In other words, once the research programme has produced successful results there remains the vital task of exploiting these results. From the scientific and theoretical point of view, this exploition consists of publishing articles or monographs, and taking out patents in order to both safeguard the results and make them known to a wider audience, thus adding to the standing and scientific reputation of the laboratory and its staff. On the practical level, exploitation, we have said, involves the more complex task of carrying the research results through to the production and sale of new output, and this, after all, is the basic objective of all directed and applied research. No-one today would presume that the transition from laboratory to production is a simple formality; it involves, in most cases, delicate and complex problems which can only be solved effectively through close co-operation between the research staff and that of development and production departments.

Evidence [1] shows that, as companies have become successful in developing more effective research orgnisations, it has become increasingly apparent that creative, innovative researchers are not enough by themselves. What is needed is an organisation which provides collaboration between scientific innovators and sales and production specialists, so that:

- the skills of the innovators can be directed at market needs and technological problems.
- sales and production specialists can be actively involved in the commercialization of ideas developed in the laboratory.

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1. e.g., Lorsch J.W. and Lawrence, P.R.: "Organizing for Product Innovation" Harvard Business Review, January - February 1965,p. 109 - 122

. and, as a result, ideas can be transferred smoothly from laboratory prototype to commercial reality.

This again stresses the importance of information flows described in the previous section. Information from the sales department about customer needs and from production about processing specifications has to be passed on to the research unit so that this information can be assimilated with the scientific feasibility of developing or modifying a product. Within the limits set by the needs of the customer and the capacities of the production process, the research units are then required to come up with a new development. If they succeed, it is then necessary to transfer information back to the sales department about product characteristics and to the production department about process specifications. With this information sales should be in a position to make and implement market plans, and production should have the data for planning and executing its task of manufacturing the product.

It is of great help if this co-operation is established while research work is still going on, and the location of laboratories and the production units close together in the case of industrial research clearly facilitates contact between them. In cases involving new production processes which present special difficulties it will often be necessary to develope a pilot plant in order to study the problems associated with the change-over from single or small batch production in the laboratory to quantity production in the completely different conditions of the production area. Here again close collaboration is essential and the research scientists must follow the progress of their work first through the pilot plant and then into production. A useful practice now becoming more common overseas is to appoint liaison engineers whose job is to maintain permanent contact between the research and production staff responsible for specific projects. The liaison engineers are generally recruited from the research laboratory and thus have the scientific training necessary to carry back and explain clearly to their former colleagues in the laboratory the problems and difficulties encountered in production. This may not appear necessary until we consider the difficulty in communication between scientists (who are mainly concerned with research) and engineers (who are concerned largely with development activities and the application of innovation). This difficulty often arises through the way in which they are trained, and there appears to be an essential difference between their respective approaches to the problem.

Engineers usually deal with something tangible - with concrete structures and mechanical devices - which can be seen and handled. Scientists, however, are normally taught to infer from experiments what the true nature of matter is. Furthermore, the primary purpose of the engineer is to make something which works and which has a practical result, whereas the scientist has been trained primarily to find out how things work. The difficulty is to reconcile these two approaches to make for more effective application of research results.

In short, innovation, if it is to be successful, requires close co-ordination between research on the one hand, and production on the other. This co-ordination is necessary not only to provide the two-way flow of technical information described earlier, but also to develope mutual trust and confidence between the members of the units which are required to collaborate in product developments. Sales personnel must have confidence in research's knowledge of science, while research scientists must have confidence in sale's appraisal of the market. Similarly, there must be mutual confidence between research and production about production's ability to operate the process efficiently according to specifications and about research's capacity to develop a process that can be operated efficiently.

Thus there is an urgent need to understand the importance of the distribution and location of scientists and engineers within the firm, and following from that the importance of adequate and effective communication and co-ordination between the various departments or divisions of personnel. An expert can remain an expert only by constantly remaining in close contact with other experts in his own particular field. It is only in such circumstances that the interchange of ideas and information so vital to original thinking can take place. This is perhaps the main justification for the existence of the universities, and research workers are not infallible - they also come out with impracticable ideas which cannot be carried out; here the scientist can only be convinced of his mistake by a fellow scientist. Furthermore, since the growing points in science are now most frequently to be found in areas lying between the traditional disciplines and involve the participation of several of them, communication on a far more intensive scale is called for, involving inter disciplinary communication and information flows. Research and development is only one part, essential though it may be, of the very complicated process of manufacturing industrial products for sale, and, as one critic has said: "industry is too serious a matter to be left entirely to scientists."

Nonetheless, the need for research and development has to be recognized, for from scientific pursuits in laboratories emerge the new ides, new techniques, new processes and new products of the factory. It is true that invention - innovation may occasionally and initially appear to by-pass this route. But no technical invention, however initiated, has been taken to fruition in industry without considerable following support from scientists and technologists who fashion the original idea to a saleable product demanding constant improvement.

To conclude then, improvements and growth have one thing in common. If one is to get past the research stage (and this stage is not an end in itself unless knowledge for its own sake is what is required), then there must be effective communication of the idea, the provision of design data, the working model, etc. between research and development, the product designers, those who have to organise the factory (its production techniques and layout), the sales force (advertising, market research, etc), and the management in all aspects. Nor is this communication one way. The feedback from sales, management, etc, to the laboratories is equally important, since through this the new objectives and market requirements give leads and direction to the research worker and to the determination of his programmes.

It is in industry in particular where one would expect the essential need for communications to be recognised and to be organised so as to facilitate the passage of ideas and information for introduction into the company's activities.

(3.) THE GENERAL EDUCATION AND ATTITUDE OF LABOUR AND MANAGEMENT.

Of primary importance in the process of innovational change is the willingness and ability of labour and management to suggest, initiate, and adopt new products, devices and methods.

"The rapid transformation of research findings by industry, in the shape of new processes and products, depends both on the organization of research and the propensity (and ability) of management, the quality of which may vary greatly from country to country, to adopt technological innovations."[1)]

1. United Nations, Some Factors in Economic Growth in Europe during the 1950's E/ECE/462 add. 1, Paris.1965.

The innovating manager, or entrepreneur, was a strongly emphasised factor in Schumpeter's theory of innovation, in which the lack of dynamic management can severely handicap improvement schemes. Labour attitudes too play an important part, for opposition to changes which affect employment or work procedures may hold up the adoption of new techniques, for example ; "Many shipyards have employed production engineering consultants to advise them on production layouts and programmes, but the implementation of such advice has frequently resulted in labour upsets, which in a period of full order books, may have made the industry as a whole reluctant to use the results of such investigations."[1)]

Not only is the attitude of labour important, but like the manager, labour must have the necessary skills and ability to accomplish innovation in the modern society. This is hardly surprising when one remembers that innovation frequently requires new kinds of capital and labour. Capital must then comprise different sorts of equipment and structures, while labour must acquire new skills and attitudes. We may often find this causes a waste of resources only recently invested in the productive processes. Furthermore, the particular kinds of capital and labour may not be available. Most innovations, in addition to permitting larger outputs or reduced inputs - occasion a change in the relative productivity of the employed factors. After making an innovation,an individual producer may find that, at the same wage and interest rates as before,he now uses more capital and less labour, or vice versa.

To return to the question of management, or entrepreneurial quality, the Technical Director of one large firm has said: "At the risk of emphasizing the obvious, I must express the firmest conviction that the biggest single factor industry has to take into account is the suitability and efficiency of the management team available at the right time for deployment in the execution of the innovation."[2)]

However, this fact is not all that obvious, and there is often merely a vague awareness of the managerial qualities necessary for innovation. To take an example, we have said that industrial research is expected to "pay off", and

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2. Carter, C.F. and Williams, B.R. Investment in Innovation, Oxford University press. London,1958. p. 77.
1. D S I R, Research and Development Requirements of Shipbuilding and Marine Engineering, H.M.S.O. London, 1960, p. 1 - 10

again the question of communications arises. The first problem is to get the research staff keenly interested in what they ought to be doing for the benefit of the industry - to engender the appropriate labour attitude - because without that enthusiasm, they could not be as creative as they ought to be. Secondly, if the research is to be fully productive, the innovation that is to result from it must fit accurately into the industrial system as that system will be when the innovation is ready to arrive there. The innovation must be compatible with the plant and the processes and the products as they will be at that time, and most important, it must be capable of being efficiently operated and maintained by the people who will be there for that purpose, and it must be suited to any particular features of its environment. As mentioned earlier, the right time to formulate these vital connections between the industry and the research is before the research starts, and they must be re-examined from time to time. In the context under discussion here, this calls for the institution of educational programmes teaching particular technical possibilities to groups of agriculturists, managers and workers in industry.

We may well ask what features of management and labour must be instilled by the educational programme and what innate characteristics must be present. The question is not easy to answer and much economic, social and psychological literature exists on the dynamism and decision - making qualities of entrepreneurs and the needs in modern industrial labour. Bright[1)] points out that a review of the early radio history has shown the importance of specialised entrepreneurial skills in the successful launching of new ventures. He mentions that the principal characteristics required were "perhaps visionary boldness, narrowness, aggressiveness, persistence, business judgement, salesmanship, the capacity to pick able associates,the delegation of authority, and the ability to inspire loyalty in a working organisation." To this must be added the all important need for the ability and willingness to promote communication and information requirements of the firm. Furthermore, an essential requirement is that managerial research personnel, and labour in general, fully appreciate that originality and innovation are most likely to flow from variety and the freedom to explore, although of course confined within reasonable bounds by company budgets and research programmes.

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1. Bright, J.L. Research, Development and Technological Innovation R.D. Irwin Inc., Homewood, Illinois,1964. p. 89.

In this connection we often encounter a type of "bottleneck" series in the various requirements under this head, for example, between:

creativity of research staff
climate for creativity
technical intelligence
experimental evaluation
economic appraisal
scale-up to pilot plant
capital available for commercial exploitation
management's attitude

At each step, resistance or absence of the required talents can be introduced and so the flow rate is established by the slowest step. The combination of the creativities of many, however, in conjunction with a favourable management-encouraged climate,leads to the sort of institutional creativity which sets a firm apart from its competitors in research achievement.

In short, what technology needs is innovation and far sightedness coupled with a full realization of the difficulties of putting new ideas into production in a profitable way.

Of note in respect of talent and technical education is the ever increasing need for a fuller awareness of the costs of research and development and what can be done to combat this. Costs of research are rising so rapidly today that in order to justify increased research and development espenditures, output must continually be increasing a little faster than the cost of research increases. Management must be made aware of this, and of possible solutions; for example there exists the possibility of automating the routine and thereby leaving more time for the creative process - "research on how to do research."

Thus, the problem goes much further than the need for highly trained staff in research and development departments. There is a pressing need for more people throughout industry who are "technically literate." They must be aware of the newest developments, eager to take advantage of them, and receptive to new ideas. They must be given the informatinn on which to make the right choices and they must know how to assess the information. The essential re-

quisites in this connection appear to be a high degree of technical excellence, responsiveness and adaptability to change on the part of general labour, a technical awareness on the part of management, and a readiness to welcome new ideas, not blindly, but critically and constructively.
The question of the labour and managerial requisites in the innovating firm must be discussed as a whole, integrating the three factors described above, namely the total supply of scientific and engineering personnel, their location and place in the firm, and the general education and attitude of labour and management. It is not enough to consider one of these in isolation, for example "because we have a large number of scientists and engineers engaged in research and development the number and importance of innovations in use by our firm is likely to be on the increase." These various aspects of the problem are both re-inforcing and competitive and a careful balance must be struck between them, so that one particular aspect is not stressed to the detriment of the others. They are all factors which complement one another and act together to promote and encourage innovation.

Of course, this somewhat complicates the issue as far as quantifying the effects of research is concerned. It is often difficult to know how far what appears to be "technical progress" is the result of the flow of new invention, of an advancement of scientific and technological know-how, or of a dynamic spirit of entrepreneurs and managers who encourage the continuous adoption of improvements and the better utilization of existing knowledge; or how far it is just the result of "learning by doing."

C. INVESTMENT:

One of the chief motivating forces for innovation has been regarded as a high rate of investment. In a more narrow context, it is not easy to design schemes from research ideas that will necessarily be limited to purely current expenditure. Model work or prototype and pilot plant construction is ideal in this connection for it is easy to try out, experiment and modify empirically so as to get optimum performance. This can be regarded as one form of investment necessary to innovation.

It must be noted that, although a popular belief, it is dangerous to expect increased investment to always increase "third factor growth" through inducing innovation. But, on the other hand, it is extremely possible that potential innovations may be slowed or completely stopped by the absence of adequate capital financing. Kendrick [1] points out that the unavailability of financing is one of the chief handicaps to technical progress, and Mansfield [2] has generally found an inverse relationship between the speed at which an innovation spreads and the size of the investment required. At the basis of Schumpeter's theory of innovation too is the importance of the entrepreneur who introduces credits into the circular flow, thus enabling the finance of innovation.

Research and development and its application is an extremely expensive undertaking, and it would seem that an essential requirement for the incorporation of know-how into the economy is investment. Thus the higher the rate of investment, the faster changes in know-how can be incorporated into the economy. We must remember, however, that not all innovation is capital-using and it may well pay less developed areas to look for capital-extensive methods (capital and skilled labour being the relatively scarce factor). Also, in highly capitalized industries where labour costs are a minute fraction of total costs, capital-saving innovations are usually sought.

We must also consider that, although scientific research and innovation may stimulate capital investment, frequently the stimulus is reversed, namely investment precedes the research or invention, e.g. investment in the development of the high-speed computer made possible research on problems not previously attempted. In a broader perspective, huge investment requirements in many industries frequently stimulate technological research in order to conserve capital.

Thus the relationship between innovation and investment is not so simple as to be dealt with in one direct relationship. Perhaps, the views of some writers on the subject would clarify the issue.

Minasian [3] for example, found that for his select sample, increases in productivity were not explained by investment, and "furthermore, investment in plant and equipment showed a consistant, but not statistically significant, nega-

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1. Kendrick, J.W. Productivity Trends in the United States, National Bureau of Economic Research, Princeton University Press, Princeton, 1961.
2. e.g. Mansfield, E. "Research and Technological Change," Industrial Research February 1964. "Technical Change and the Rate of Imitation, Econometrics Volume 29, 1961. "Intrafirm Rates of Diffusion of an Innovation," Review of Economics and Statistics, November, 1963.
3. Minasian, J.R. "The Economics of Research and Development," The Rate and Direction of Inventive Activity, op cit. p. 93 - 141.

tive correlation with investment in research and development. This suggests that the two types of investment may be competitive rather than complementary in nature." Similarly, a team from Batelle Memorial Institute (USA) under O.W. James, believes that research and development and capital investment may be regarded as alternative uses for coporation funds.

Schmookler [1] says regarding:

(i) the railroad industry - that the "introduction and diffusion of inventions seems merely to accompany, but not to cause the waves of investment." He postulates instead that trends in invention are caused by either trends in investment or the same forces that shape investment (chiefly maximum use of existing capacity).

(ii) agriculture and papermaking - that important inventions seem to lead investment and he speculates that causality may run from major inventions to investment to more "adjustive" inventions, all these points subject to the limitations of patents to inventions affecting innovation.

On the other hand, Dr. L.C. Kemp [2] points out that there is no inherent virtue in research and development percentages, just as there is no inherent virtue in high rates of capital expenditure. He regards them as both being parts of the investment process and, as such, constitute costs of growth. Optimum allocation of resources, then, involves taking investment in research and development (and innovation), as well as in plant and equipment, to the point where prospective yields to additional expenditure equal the cost of the finance involved.

Mansfield [3] points out that the rate of diffusion (and technological progress is dependent upon this rate) tends to be higher for more profitable innovations, and for those requiring relatively small investments, and that the rate of diffusion tends to be higher when the innovation does not replace very durable equipment.

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1. Schmookler, J. "Changes in Industry and in the State of Knowledge as Determinants of Industrial Invention" Ibid, p. 195 - 232

2. Kemp, L.C. Transition to Production , —

3. Mansfield, E. "Technical Change and the Rate of Imitation," Econometrics Volume 29, October , 1961.

From the above different view points, it can be seen that there is no complete unanimity on the subject of investment and innovation, and it would be unwise to generalize that investment must, in every case, precede innovation, although the likelihood of it so doing is great. We have seen how the 'residual economists' (like Solow and Fabricant) attribute from 75% to 90% of the output increase per head to technological change. We must remember, however, that although much of what we refer to as technical change consists of organizational changes which require no new inputs, a much greater portion of changes in the technology are probably embodied in capital goods of some form. Thus there is strong reason to believe that the rate of technological advance will be influenced by the rate of capital formation. A more direct relationship probably exists between changes in technological and gross investment, for innovations are often embodied in capital goods which represent, not additions to the capital stock, but replacements of existing capital. Technical change will thus flourish most in an economy which is expanding its stock of capital. Conversely, we should expect the rate of net capital formation to be greatest when there is a high level of innovational change, for the rate of profit is then likely also to be high.

From another angle, one can regard the rate of net investment as being definitionally determined by the rate of technological advance. Given the rate of gross investment, the rate of net investment depends on the rate of deterioration and obsolescence of capital stocks. The former is largely economically determined while the latter is a technological consideration. In other words, obsolescence is greater the larger the rate of innovational change. There is thus a link between innovations and capital formation so that the latter is defined partly in terms of the former. Therefore, while we have found technological change of considerable importance in raising productivity, further research would be needed to predict, for example the effect on per capita output of alternative rates of capital accumulation and of technological change.

From the above, it can be seen that the traditional treatment of technology as an exogenous factor in production theory is thus basically wrong. Further, there is little justification for considering the rate of investment as exogenous, for expenditure on research and development will certainly effect this variable, and such expenditure in influenced by other economic magnitudes. There is still less justification for considering the rate of innovation as exogenous, for given the rate of invention, the rate at which new ideas are adopted is a function of such variables as the level of aggregate economic activity, the profit rate, the age composition of the capital stock, and investment factors in general. Economists would thus do well to consider these variables as determining, at least in part, the rate at which innovational change occurs.

D. ECONOMIC ENVIRONMENT AND MARKET STRUCTURE

In an earlier section, the general economic environment necessary for economic growth was described, and obviously the same conditions must be present in order for innovation decisions to be made. A favourable "infrastructure" is necessary for innovation as a factor of growth. This must include inter alia, normal competition, either internal or external, protection and opportunity for profits, a relatively stable economy, and the ability to predict risks and future movements; the availability of capital and the capacity for innovation.

It can be seen that some of these factors relate strongly to the factors affecting innovation discussed previously. Other important subjects under this head are:

(a) Size and competition

In this section, a frequent source of controversy is the question as to whether innovation flourishes more in an environment of monopoly or of competition. Many economists adhere to the traditional view that competition begets technical progress, that the competitive spur goads firms on to make innovational change and thereby increase their share of the market. But the Schumpetarian hypothesis, probably the oldest and most respectable on this subject, asserts that the possession of accumulated monopoly rewards, the prospects of additional such rewards in the future, and the security attending market power are prerequisites to undertaking the risks and uncertainty of innovational activities.

Innovation involves change and uncertainty, particularly when the change is fairly radical, and it is understandable that a small firm is reluctant to undertake the investment risk, particularly where the rewards from that risk are likely to be shared through imitation in a competitive market. A recent survey by the National Science Foundation (USA), for example points out that company-financed research and development effort in the United States is highly concentrated in large firms making up, for the most part, the economy's most highly concentrated industries. Five industry groups - chemical and allied products (17%), electrical equipment and communications (19%) motorvehicles and other transport equipment (14%) machinery and aircraft and missiles (25%) - accounted for approximately 75% of all company-financed research and development.[1)]

Mansfield[2)] also examines the theory that it is mainly in large firms that innovation should take place, because:

1. the cost of innovations is generally high,
2. new projects should affect only a small part of a large whole, so that the failures may be covered by the successes,
3. the profitability of innovations depends on the firm having sufficient control over markets to be able to reap large rewards,
4. large firms are more dynamic and have better managerial talent.

Mansfield finds that the four largest firms (as far as sales indicate) in the petroleum refinery and coal industries in the United States are responsible for a relatively larger share of innovations (judged by the latter's relative importance for cost savings and sales volume), but for a less than proportionate share in the iron and steel industry. His findings indicate that the Big Four firms account for a greater than proportionate share when:

(i) the investment required is large,
(ii) the minimum size of the firms which will use the innovation is large,
(iii) the average size of the four largest firms is very much greater than the average size of the potential user (that is, they will tend to profit more).

In his studies on Imitation [3)], he finds that, once they begin, innovation in small

1. NSF, The Structure and Dynamics of the R and D Industry, Washington, 1964.
2. Mansfield E.; "Size of Firm, Market Structure and Innovation," Journal of Political Economy, December, 1963.
3. Mansfield, E.; Econometrics "Technical Change and the Rate of Imitation," Volume 29, October 1961.
"The Speed of Response of Firms to New Techniques," Quarterly Journal of Economics, Volume LXVIII, May 1963.
"On the Rate of Diffusion of Diesel Engine," Econometrics, 1962.

firms tends to diffuse as rapidly as large firms, but they are slower to initiate an innovation. Moreover, as a result of competition, there may be more would-be users of a process innovation, but fewer for a product innovation since this may be less profitable if others use it.

Peck [1] concludes that, for the aluminium industry, innovations in equipment are induced mainly by competition since there are a large number of equipment manufacturers. In contrast, he says that primary and end-product innovation usually comes from the relatively large aluminium companies.

Comanor [2] is of the opinion that firm size appears to have acted to increase the gains resulting from new product introduction, and these gains increased more than proportionately with the size of the firm. Furthermore, the relationship between research and development and the rate of technical change is substantially influenced by the size of the firm. He maintains also that, not only is the relationship affected in total by differences in this variable, but the functional form of the relationship too is dependent on these values. Towards the lower end of the size distribution of firms, economies of scale in research appear to be present, while diseconomies of scale are likely when the firm size becomes larger.

Galbraith J.K. [3] has this to say: "A benign providence, who, so far, has loved us for our worries, has made the modern industry of a few large firms an almost perfect instrument for inducing technical change." The reason he gives for this opinion is twofold:

(i) the situation gives firms the financial ability to undertake technical development, and

(ii) it provides the incentives necessary for innovating.

Research and development, he argues, is expensive and risky today and only large firms can afford the effort. And unless the firm has substantial market control precluding effective price competition while allowing for technical chan-

1. Peck, M.J. "Inventions in the Post War American Aluminium Industry," The Rate and Direction of Inventive Activity, op. cit. p. 279 - 322
2. Comanor, N.S. "Research and Technological Change in the Pharmaceutical Industry," Review of Economics and Statistics, May 1965, p. 182 - 190.
3. Galbraith, J.K. American Capitalism, Harvard University Press, Cambridge, Massachusetts, 1952, p. 91.

ges, the returns from the innovation are apt to fall into the hands of imitators before the innovator has reaped his reward.

Philips [1] subjects the above hypothesis to some empirical tests to see whether, in those industries in which production is concentrated in a few firms, and in which firms are large relative to those in other industries, either, or both, of these conditions exist. He concludes that, in general, it has been found that such industries do show more signs of innovational change.

Frequently, criticism is levelled at the gap between an advance in applied research and its application, particularly by small- and medium- sized firms. Critics point out that it is almost certainly no co-incidence that senior management in such firms does not, in general , have a scientific outlook and employs far fewer qualified scientists and engineers, even as a proportion of their total labour force, than do large firms in the same industry. Fortunately, this is not true of all firms, such as the progressive firms in the electronics industry and other small firms who provide happy exceptions.

A similar lack of interest in scientific developments at lower levels may result from the normal system of apprenticeship (present to a large extent in smaller firms lacking a scientifically developed training programme) which tends to turn out people skilled in the use of older techniques rather than those who have the flexibility to apply new ones. [2] The economy is also heavily handicapped by deficiencies in technical education which prevent many firms from having anybody on their staff capable of understanding the terminology in which scientific information is presented. Dr. T. Emmerson of the D S I R in Britain has this to say: "The inability to make effective use of the inflow of technical information was not regarded as surprising. The small firm frequently has no one capable of understanding the concepts and terminology used in technical literature and of translating the ideas into his own surroundings."

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1. Almaran Philips, "Concentration, Scale and Technological Change in Selected Manufacturing Industries," Journal of Industrial Economics, Volume 4, 1955 - 56. p. 179 - 193.
2. Gertrude Williams, Apprenticeship in Europe, Chapman and Hall, 1963.

What conclusions can we draw from the above? From the available evidence it would appear that size is not quite as important in the basic discovery, but size is vital in the development of the system which will make it possible to apply these discoveries. The innovational process is expensive and risky, and ever soaring research and development costs are steadily reducing the number of firms rich enough to stay in the technological race on their own. For example, it has been said that for every £1 spent on research in the United Kingdom, £10 must be spent on the prototype and £100 before the product is marketable [1]. Only large firms can afford this effort, and, without a certain amount of market control, firms will be unwilling to undertake the effort.

Thus the trail of innovative effort would seem to lead to the doors of the large concerns operating in markets distinctly not characterized by all the conditions of free competition. There are, however, two important qualifications that must be made here. The first is that, although some departure from a state of perfect competition (or the presence of some monopoly) appears a necessary concomitant of innovation, it does not follow that twice this volume of departures, somehow measured, should lead to twice the volume of innovations. Secondly, it need not be inferred that all big firms and oligopolists innovate and that absolute monopoly must prevail. Accordingly, it would be erroneous to regard the advent of the scientific and technological revolution as heralding the death knell of the small firm. Clearly, in a number of industries technological development calls for large units if the greatest rewards are to be obtained. But optimum size is not synonomous with gigantic size. Developments in the use of energy and in the application of some forms of automative equipment have shown how big plants were required at the outset, but later it proved possible to use the most modern techniques in smaller plants. As an example, American General Electric's laser factories are quite small, with anything from 50 - 1500 employees and 50% of General Electric's sales are produced by independent small subcontractors. It is not size as such then that provides the strongest argument for innovation, but rather optimum size and co-operation on a firm, national, and international scale.

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1. Times Review of Industry and Technology, Volume 4 No. 5, May 1966.

(b) <u>Other Environmental Factors</u>

There have been very few theories or empirical studies on the effect of other economic conditions on innovation. It would be reasonable to expect that a stable economic growth and long-range predictions of the areas of government expansion would benefit business planning, viz. the experience of co-operative planning, and projection in Europe and increasingly in Britain. (Government influence in general on innovation will be considered at some length in a later section). It also seems that a slight surplus of demand over supply, and gentle inflation tends to stimulate "induced innovation."

Mansfield [1] has studied the effect of the business cycle and other historical trends on innovation and concludes: "It appears that process innovations were most likely to be introduced during periods when the industries were operating at about 75% of capacity. Contrary to the opinion of many economists, there was no tendency for process innovations to cluster during the periods when operating rates were extremely high or extremely low. Apparently innovation at the trough was discouraged by the meagreness of profits and uncertainty regarding the future. At the peak, some executives in the industries claim that it was dicouraged by the lack of unutilized capacity, where alterations could be made without interfering with production schedules."

One specific and important area of consideration in the environmental factor is the attitude of acceptance of, or resistance to, the proposed innovation. Anyone introducing a technological innovation is implicitly or explicitly predicting acceptance and a rate of adoption. The assumption seems to be that, since the innovation provides greater service or a feeling of increased satisfaction to users than does its present equivalent, or because it is economically justified, it will be adopted. Yet a fact of technical history is that many innovations are subject to frustrating delays and deliberate resistances to adoption, so that the result is frequently an economic reversal.

While a complete analysis of the process of adoption of technological innovations is not possible here, it clearly depends upon many things, such as economic, cultural, technological, political and social factors and the response of the influential decision makers. Practical and effective innovation hence requires not only that new ideas and methods should be devised; it requires that people should use

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1. Mansfield E.: "Research and Technological Change," <u>Industrial Research</u>, February, 1964.

them; and firms must not only be ready to accept new ideas - they must welcome them. Technical and financial aid measures can be effective then only in so far as they are geared to a sociocultural change that releases and encourages attitudes which, in the social and economic structure, have been neglected or repressed, e.g. curiosity, willingness to take risks, inquisitiveness, ambition, initiative, social mobility and the widest possible participation of the greatest number of people.

There is one aspect of the problem which deserves attention here, and that is the explicit act of resistance to technological innovation. By recognising this resistance, the innovator may be able to achieve his goal more rapidly, and, in addition, may be able to delay or reduce the impact of competitive innovation. A summary of the more general reasons for resistance to technical change is given below. In other words, a technological innovation is opposed:

1. to protect social status or prerogative,
2. to protect an existing way of life,
3. to prevent devaluation of capital invested in an existing facility, or in a supporting facility or service,
4. to prevent a reduction of livelihood because the innovation would devalue the knowledge or skill presently required,
5. to prevent the elimination of a job or profession,
6. to avoid expenditure, such as the cost of replacing existing equipment or of renovating and modifying existing systems to accomodate, or to compete with innovation,
7. because the innovation contradicts social systems, fashions and tastes, and the habits of everyday life,
8. because the innovation conflicts with existing laws,
9. because of rigidities inherent in large or bureaucratic organizations,
10. because of personality, habit, fear, equilibrium between individuals or institutes, status, and similar social and psychological considerations,
11. because of organized groups to force conformity,
12. because of reluctance on the part of an individual or group to disturb the equilibrium of society or the business atmosphere.

Thus, it can be seen that research and development is only one of five main factors which must be present to a greater or less extent before successful technological innovation can take place. Nor do these factors cease to operate once innovation occurs; they must continue to exert an influence in order that economic growth may ensue.

Carter and Williams [1] list a number of "characteristics of technically progressive firms", and the factors already discussed can be seen to be present to a considerable extent in these characteristics. The characteristics listed are:

1. good information sources,
2. seeking outside standards of performance,
3. no secretiveness,
4. readiness to co-operate,
5. good co-ordination,
6. ideas surveyed,
7. cost consciousness in research,
8. quantified investment decisions,
9. good management techniques,
10. high status of science,
11. scientists on the Board,
12. good chief executive,
13. attractive to talent,
14. good recruitment policy,
15. good training policy,
16. tough intermediate managers,
17. good intermediate managers,
18. managers stimulated,
19. effective selling,
20. good technical service,
21. ingenuity with shortages,
22. forward-looking tendency,
23. high expansion rate,
24. rapid machine replacement,
25. industry scientific,
26. good buildings,
27. top manager a scientist,
28. shop-floor resistance to innovation (low)
29. adequate finance.

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1. Carter C.F. & Williams B.R. "Characteristics of Technically Progressive Firms" Journal of Industrial Economics, Volume 7, 1958-59, p. 93

On the basis of ratings obtained in this list, the authors divide firms into:

(a) those which are in the forefront of discovery in applied science and technology, quick to master new ideas and to perceive the relevance of work in neighbouring fields,

(b) those which are quite uninterested in science and technology, and are perfectly content to continue with traditional methods without even examining the alternatives, and

(c) a large middle group, neither outstanding leaders in technology nor wholly uninterested in it.

The first of these will obviously include favourable answers to the characteristics listed above and will contain most of the factors influencing innovation discussed previously. These technically progressive firms are those likely to have experienced growth (as a result of the successful adoption of innovation) or are likely to experience such growth in the immediate future. For example, in the United States, it is claimed that the rapid growth of firms in the chemical, electronics, and allied industries has been largely due to technical progressiveness, or the awareness of, and response to, technological innovation:

"The public has profited greatly from the chemical industry's long term, consistently aggressive research policy. The selling price of chemicals has remained substantially constant for the past 30 years, while the cost of most of the things we buy has more than doubled. The sales of chemicals and allied products last year were about $ 34B. Without the innovation and advance of technology that have come at least partially from research and development, they could have cost $ 68b. And, of course, many of them we would'nt have at all". 1)

"In the petroleum industry, and in most industries today, there is no question in management's mind as to the value and necessity of research. We have seen many examples of what research can do. Indeed, the present day petroleum industry is largely a demonstration of what research has done to improve products, increase yields, cut costs and increase the scale of operations. If we tried to evaluate what research has done for our industry, the figure would run into billions of $, and, at the same time, research has done even more for the consumers of petroleum products (while the index for all consumer goods has risen about 35% since 1925, the price index for gasoline in a similar comparison has risen but 2%". 2)

It must be remembered that, although the above quotations illustrate the importance of research, the effect would not have been made without the co-operation of the other factors mentioned, in other words the technical progressiveness of the firms allowed them to grow and engendered the benefits named.

The above discussion has centred mainly on the characteristics and effectiveness of private industry in the innovational process. It now remains to consider the

1. Bounty R.H., "Automation in the Research Process" Research Management, Volume VII, (5). 1963.

2. Wilson R.E., In Chemical and Engineering News, Volume XXVII, 1949.

role of government (the biggest spender of research and development funds).

4.4 GOVERNMENT ACTION AND TECHNOLOGICAL INNOVATION

To emphasise the importance of government action as a factor in stimulating innovation is to make two explicit assumptions:

1. That economic growth is desirable and that it is one of government's functions to foster it as far as is compatible with its own policy aims.
2. That one of the determinants of economic growth in a technological society is the speed at which firms are able to apply the results of scientific advances to achieve greater efficiency.

On the basis of these assumptions, it can be seen that the government should seek to increase the alertness of industry to relevant discoveries, and, in particular, it should attempt to improve the performance of those industries which seem noticeably slower at applying innovations than the nature of their productive process might warrant.

According to Baker [1] it is "unnatural for a government to sponsor innovation," but private enterprise is often hindered in integrating its innovations by size and by antitrust measures. Size, also has an important consequence for government action since the size alone of government expenditures on research and development activities [2] merit close attention by government to the returns from that research. We have seen how other circumstances, such as the unwillingness or inability of private firms to undertake research and innovation, have led to government intervention in what we have called 'public sector research and development'. Now we must consider what other effects governments have on innovation.

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1. Baker, W.O.: The Dynamism of Technology, —
2. Table 11 on page 118 gives an indication of government committment to research activities in various overseas countries. As can be seen, the contribution to financing of research activities made by governments is considerable, representing in most cases well over 50 per cent of the total funds devoted to research and development activities.

   Preliminary estimates of the extent of government sources of funds for research activities in South Africa also show considerable state support for research, representing more than 75 per cent of total funds devoted to research and development activities (excluding the contribution of private industry.)

This whole question brings us back to the subject of science policy. Science policy consists of many elements and maximum benefit from the overall research activities can be achieved only when all these elements are suitably developed and work together in a well balanced system. This calls for government intervention, both direct and indirect in a number of related fields, the basic essentials for which include:

1. The need for fundamental research activities both for education, and as a base for all further research. Government support for fundamental research influences the technical opportunities for innovation in the long term, since basic research is often an essential pre-requisite for much applied research, development and technological innovation.
2. The need for the creation of applied research institutes in fields which are not covered by industry itself. Furthermore, government requirements for technologically advanced equipment, especially in relation to military and space programmes, lead to innovations which may have a civilian application, whilst at the same time, absorbing a large number of qualified scientists and engineers. This is of particular note when one considers government commitment in these fields. [1)]
3. Government policies for education and re-education have very important repercussions on a firm's technical and managerial capacity to innovate, and on the attitudes of both management and labour towards innovation.
4. Government policies towards monopolistic practices together with the level of the external tariff influence the degree of competitive pressure on firms to innovate. In this connection, note that patent legislation and practices also influence the incentive which firms have to introduce an innovation for the first time, as well as the speed with which such an innovation is diffused throughout the whole economy.
5. Specifically in the field of applied research, it is considered essential that good collaboration be established between research institutes of all kinds and industry, for example by the participation of industrialists in research councils, on the boards of research institutes, and on various re-

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1. See Table 12 page 119.

search reviewing committees. Similarly, there is need for achieving the right balance between research efforts in research institutes and in industry itself, for example through research contracts to industry and prudent legal measures (tax concessions, depreciation policies, etc.) Government sponsored institutes may take a worthwhile lead in the above.

6. The nature and attitude of financial institutions influence the availability of risk capital for innovation, and the level and steadiness of economic growth influence incentives and opportunities to innovate.

7. Particularly for a small country, international research co-operation is an important part of the overall national science policy. In this context, government action to promote the international exchange of scientific information through documents, conferences and personal contacts has always been important. The creation of the international research organization (C E R N, E S R O, etc.) has lately made international research co-operation a government responsibility of significance to overall scientific activities.

Government action in the above fields can help considerably to create the general climate for technological innovation throughout the economy. Such action may not, however, be sufficient to stimulate an adequate rate of technological advance in all economic and technological sectors. We have seen how in certain sectors, such as environmental pollution and the conservation of natural resources, new collective needs of the community sometimes cannot be satisfied through private initiative, so that the government must assume responsibility to do so. In addition, government laws, related for example, to safety requirements, monopolistic practices and fixing of prices in regulated industries, may hinder innovation in certain sectors and therefore need to be modified. Furthermore, the depreciation policies and the regulation policies of government may sometimes act to obstruct innovation; for example, when the government decides that it will be to society's benefit to subsidise or allow more liberal depreciation policies to hasten the junking of obsolescent plant and equipment, business and potential innovators will take advantage of this.

Direct government action may also be necessary in sectors where the normal forces of competition do not create favourable conditions for technical innovation. This may occur in technically old-established sectors, such as agriculture where firms may be unaware of the commercial value of innovation and may not be competent to use information from other industries, or innovation by suppliers of equipment and raw materials is unlikely to stimulate innovation. In such sectors, co-operative research institutes and technical information and advisory services may be established with government aid and encouragement.

Direct government action may be necessary too in science intensive sectors such as nuclear energy and civilian air transport, where firms are aware of the possibilities for technical innovation but are not large enough to devote manpower and financial resources to innovation on a scale large enough to be effective. In such sectors, the government may encourage co-operations and even mergers between firms, give fiscal advantages, use civil development contracts and have a deliberate policy for the procurement of technically advanced products. This (i.e. an extension of civil development contracts) presents a possible means of concentrating the scarce resources of scientifically trained manpower into those sectors of the economy where they are likely to have the greatest effect on future economic growth.

Many of the above measures on the part of government to stimulate innovation result from the concept of size - the need for a large-scale committment of resources (both financial and otherwise) to innovational activities which private enterprise cannot supply in many instances: of course the vast financial commitment of governments themselves to research and science policy matters serves to make them extremely aware of the measures to be taken. In view of the increasing volume of government financed research, the exploitation of the resultant inventions is of growing importance. This is particularly relevant when one considers that the gain to users, the general public and in may cases, the government directly, from innovation may well be a considerable multiple of the sales price. These considerations, among others, justify special measures of support from the government to encourage the pre-manufacturing stage of new products and to ensure that potentially useful inventions, unsponsored by industry, are carefully investigated. The difficulty here is, as we have seen, that the commercial interest of an exploiting organization often opposes the public interest and government action is necessary for a compromise.

In the long term, a complete solution to the problem of bridging the all-important gap between successful research and its application can be achieved only by a sustained effort both to improve education, especially technical education, and to make the business environment more competitive.

The following broad means which can be taken by governments in the short term to accelerate the adoption by industry of scientific innovations are suggested:

1. Methods by which the government can direct the attention of industry to fields of production bearing upon the efficiency and growth potential of the economy as a whole. Government action here would merely comprise indicating the field for the innovational activity and persuading firms to enter it by some of its measures outlined above.
2. Those measures concerned with scientifically unsophisticated firms and deal with the means by which they learn of, and apply, scientific innovations. The key to this is the dissemination of relevant information in a form that small and medium-sized firms, lacking scientific expertise, can assimilate and act upon. In this way, the scarce factor of scientifically trained manpwer can be used more efficiently than would be the case if each firm had to rely on its own scientists to provide it with technical information.

These measures again illustrate the importance of communications. Many ideas which may lead to new products originate within industry and are used directly by the originating firm. A major block to inventions and research results, however, originates outside industry and, in such cases, communications need to be established between the inventive source and the user. To facilitate the utilization of inventions originating particularly within government departments, but also from universities, private inventors, etc., the National Research Development Council was founded in the United Kingdom in 1949. Its functions are to secure, where public interest requires, the development or exploitation of inventions resulting from public research or from other sources.

In all its actions, the government must be careful to promote stability and confidence in the economy. Whatever concessions, e.g. taxation allowances, are granted to research and development activities (and these concessions on research and development expenditures are far from negligible overseas) the application of these innovations to industry counts as normal capital expenditure and is subject to the constraints which, from time to time, are exercised by government on investment. Investment in a new product or process is always to some extent a gamble and this gamble is greatly intensified if business believes that future demand is likely to fluctuate considerably as a result of, for example government expenditures on a large scale.

4.5 SUMMARY AND CONCLUSIONS

We have seen how the use of science in agriculture, industry, medicine and public services has made possible enormous increases in population, material standards of living and life expectations.

Research has been considered by many as being the key factor in this growth, in particular the expenditure on research. However it is obvious that there is no logical step from the observed effects of applied science on past growth to the conclusion that national expenditures on research are the keys to future economic growth. We have noted that research as such is simply a process of adding to scientific knowledge. Sometimes new scientific knowledge has a direct influence on the technology embodied in production processes. Frequently, however, a further (and usually far more costly) activity called development is required before science can affect technology. Hence, throughout, we have referred to research and development, as a growth factor. We have called these rather special cases 'technological change in the narrow sense' (i.e. innovations) and restricted our discussion to research - based, or scientific, innovations.

Clearly, technological change in the narrow sense may take place without new knowledge resulting from research and development activities. It may, for example, result from minor modifications of existing products and processes. Indeed, Professor Jewkes[1] has said: "There is no evidence which establishes definitely that technical or economic progress receives greater contributions from the few and large advances in knowledge than from the many and frequent small improvements. Economically, it might for a period well pay a community

1. Jewkes, J, Sayers D, and Stillerman, R.; The Sources of Invention, London, Macmillan and Co. Ltd., 1960. p. 6.

to starve scientific and major technical work and to devote resources to the most thorough and systematic gathering together and exploitation of all the immediate and tiny practical improvements in ways of manufacture and design."[1]

Equally, technological change may result from the direct installation of already existing techniques and, from the point of view of a given firm/industry/country, research and development may not be required at all, e.g. we have mentioned the purchase and flow of knowledge.

In the second place, even where research and development is called for, the research and development input in itself will nearly always be insufficient to get technical change. It is the application of research or technology (and the efficient use of it) that is critical in growth. One of the applications of research, namely in the form of technological innovation, has been dealt with fairly extensively, especially the factors influencing innovation. They illustrate the danger of regarding research and development as the necessary and sufficient condition for economic growth. It is only when one takes into account these other factors, and in particular the receptiveness to technical change, that research and development can be legitimately regarded as being instrumental to the promotion of economic growth, or, as Kuznets[2] terms it: "research and development becomes both the necessary and sufficient factor."

It is not inconceivable from the above then, that for long periods scientific advance may lie wholly in fields which have no immediate, or even ultimate utility in the narrow sense - these other factors may be wanting. Furthermore, it is not inevitable that the country with the outstanding scientific achievements will be the richest country. Indeed, it is often suggested that, even where scientific advance has ultimately contributed to technology, the lag has been so great that it automatically rules out the possibility either of prediction or of calculated investment to produce results.

"Any community, therefore, which deliberately invests in pure science solely as a way of producing returns in technology and invention is not merely setting out on a course which threatens the ultimate values of science itself, but is also engaging in a blind gamble." [3]

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1. Jewkes, J. Sayers, D. & Stillerman, R.: The Sources of Invention, London, Macmillan and Co Ltd., 1960, p. 6.
2. Kuznets S.; Six Lectures in Economic Growth, The Free Press, Chicago 1964.
3. JewkesJ; Sayers, D. and Stillerman, R.: The Sourcesof Invention, London, Macmillan and Co. Ltd, 1960 p. 7.

Table 7.

ESTIMATED "TECHNOLOGICAL BALANCE OF PAYMENTS"

($ millions, at official exchange rates)[1]

	Receipts	Payments	Balance	Ratio of Payments To Receipts
1. Transactions with all countries, all industries				
U.S.A., 1961[2]	577	63	+ 514	0.1
France, 1962	40	107	- 67	2.7
Germany, 1963	50	135	- 85	2.7
2. Transactions with U.S.A. only, all industries				
France, 1962	11	53	- 42	4.8
Germany, 1963	10	52	- 42	5.2
United Kingdom, 1961	17	86	- 69	5.1
Western Europe (including others), 1961	45	251	- 206	5.6
3. Transactions of particular industries with all countries				
(a) Germany (1963)				
Chemicals*	19.3	33.8	- 14.5	1.7
Electrical Machinery	10.7	29.0	- 18.3	2.7
Machinery	14.2	45.2	- 31.0	3.2
(b) France (1960)				
Chemicals*	10.3	14.0	- 3.7	1.4
Electrical Machinery	1.7	12.6	- 10.9	7.4
Machinery	0.2	4.1	- 3.9	17.2
(c) U.S.A. (1956)				
Chemicals*	34.1	10.7	+ 23.4	0.31
Electrical Machinery	21.0	0.7	+ 20.3	0.03
Machinery	28.2	1.3	+ 26.9	0.05
Vehicles	16.6	2.3	+ 14.3	0.14
4. Transactions of particular industries with U.S.A. only				
Germany (1963)				
Chemicals*	7.5	13.5	- 6.0	1.8
Electrical Machinery	0.9	13.5	- 12.6	14.9
Steel, machinery, vehicles	2.5	16.2	- 14.1	7.1

* Including petroleum products.

. It should be remembered that only a part of the total flow of techncial know-how can be measured.

. The unadjusted 1961 figures were $ 707 millions (receipts) and $ 81 millions (payments). These figures include some non-technical payments. On the unadjusted basis the 1962 figures were $ 807 millions (receipts) and $ 104 millions (payments).

OURCE: FREEMAN C. and YOUNG A. The Research and Development Effort in Western Europe, North America and the Soviet Union, Op. cit. p. 74.

Table 8.

EXCHANGES OF TECHNICAL AND SCIENTIFIC DOCUMENTATION BETWEEN THE SOVIET UNION AND SIX MEMBERS OF THE COUNCIL FOR MUTUAL ECONOMIC ASSISTANCE, 1950 TO 1958

	Bulgaria	Czecho-slovakia	Eastern Germany	Hungary	Poland	Rumania	Total
Capital Construction Projects							
Received by Soviet Union	8	37	5	9	15	4	78
Handed over by Soviet Union	152	99	21	199	110	84	585
Blueprints of machinery and equipment							
Received by Soviet Union	15	344	164	108	112	69	812
Handed over by Soviet Union	322	387	90	269	380	282	1,730
Description of Technological Processes							
Received by Soviet Union	35	271	101	179	103	53	742
Handed over by Soviet Union	197	239	105	190	213	102	1,046

Source: Alhimov V. and Mordvinov V. "Foreign trade of the U S S R", Soviet Booklet, No. 37 (p.17), reproduced in Some Factors in Economic Growth in Europe during the 1950's, United Nations, E/ECE/452, Paris 1964.

Table 9.

PATENT STATISTICS.

	Total number of patents taken out		Percentage taken out by foreign applicants		Percentage taken out by U. S. A. applicants		Percentage of total taken out in U. S. A.	
	1952-56	1957-61	1952-56	1957-61	1952-56	1957-61	1952-56	1957-61
Belgium	45 406	57 904	81.2	85.1	15.0	17.2	0.2	0.2
France	142 300	157 700	48.3	59.4	11.0	17.1	1.4	1.7
Germany	126 342	103 076	22.4	32.4	5.8	11.5	2.0	4.2
Netherlands	14 620	16 352	68.9	74.5	16.4	17.7	0.8	0.8
United Kingdom	184 095	218 995	41.7	47.0	16.5	18.4	3.7	3.6
Total "Western Europe"	513 363	554 027	43.0	52.6	12.2	16.7	8.1	10.5
Canada	56 696	100.133	94.2	94.7	65.6	69.4	1.1	1.2
Austria	20 183	29 680	60.5	75.9	5.6	6.8	0.1	0.2
Denmark	9 090	9 735	72.0	79.3	10.6	12.3	0.1	0.1
Ireland	2 130	4 361	81.0	87.5	13.4	16.0	x	x
Italy	85 400	77 698	55.0	62.7	11.4	17.0	0.3	0.5
Norway	8 985	10 676	71.3	80.0	12.4	14.0	0.1	0.1
Sweden	22 978	20 344	64.2	68.8	17.3	16.6	0.8	0.8
Switzerland	38 285	41 050	56.8	64.8	8.7	11.9	1.1	1.2

x Negligible.

Source: Journal of the Patent Office Society, Washington. February 1964.

ESTIMATED MANPOWER ENGAGED ON RESEARCH AND DEVELOPMENT 1962.

	Scientists and Engineers engaged on Research and Development	Other Personnel engaged on R & D	Total Personnel engaged on R & D	Total Population	Total Working Population (aged 15 - 64)	R & D Personnel per 1 000 Population	R & D Personnel per 1 000 Working Population
	('000's full-time equivalent)	('000's)	('000's)	(millions)	(millions)		
UNITED STATES	435.6	723.9	1 159.5	186.6	111.2	6.2	10.4
WESTERN EUROPE *	147.5	370.8	518.3	176.1	113.9	2.9	4.6
BELGIUM	8.1	12.9	21.0	9.2	6.0	2.3	3.5
FRANCE	28.0	83.2	111.2	47.0	29.1	2.4	3.8
GERMANY	40.1	102.1	142.2	54.7	36.7	2.6	3.9
NETHERLANDS	12.6	20.2	32.8	11.8	7.3	2.8	4.5
UNITED KINGDOM	58.7	152.4	211.1	53.4	34.8	4.0	6.1
U S S R 1.	416	623	1 039	220	142	4.7	7.3
U S S R 2.	(487)	(985)	(1 472)			(6.7)	(10.4)

* Belgium, France, Germany, Netherlands, United Kingdom.
1. "Conservative" estimates.
2. "Project" assumptions.

SOURCE: Freeman, C. and Young, A. : The Research and Development Effort in Western Europe, North America and the Soviet Union. Op. cit. p. 72.

Tabel 11.

ESTIMATED GROSS EXPENDITURE ON RESEARCH AND DEVELOPMENT BY SECTORS OF THE ECONOMY, 1962 PERCENTAGES

	Performance			Source of Funds		
	Business enterprise sector	Higher education sector	Government and non-profit sectors	Business enterprise sector	Higher education sector	Government and non-profit sectors
United States	71	10 1)	19 3)	35	2	63
Western Europe*	59	12	29	43	x	57
Belgium	65	13	22	63	x	37
France	48	14 2)	38	30	4)	70
Germany	61	20	19	60	x	40
Netherlands	60	14	26	65	x	35
United Kingdom	63	5	32	36	x	64

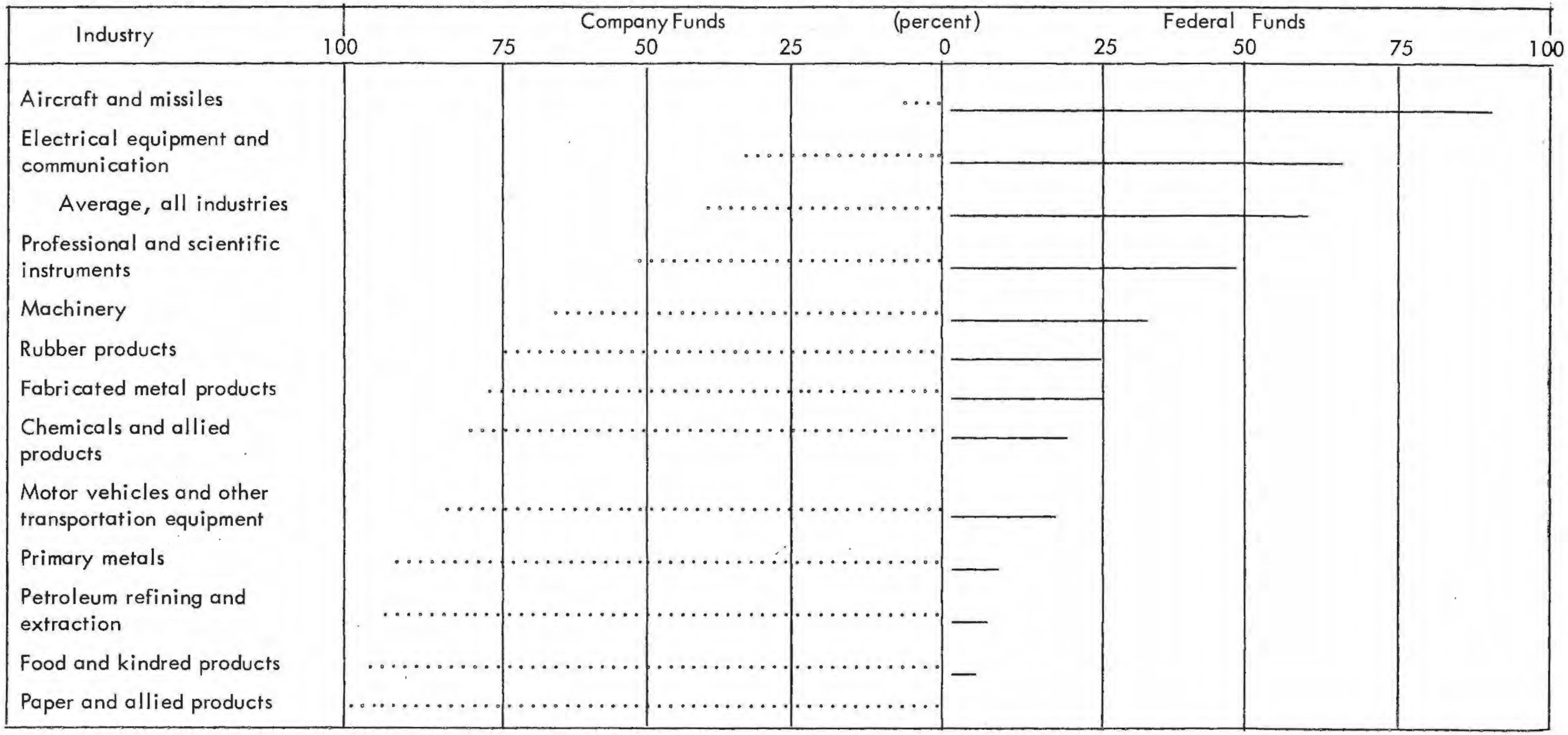
* Belgium, France, Germany, Netherlands, United Kingdom at official Exchange Rates.
x Negligible

1) Including Federal Contract Centres (3%)
2) Including C N R S (5%)
3) Non-profit (3%) Government (16%)
4) Included in "government and non-profit sectors".

Source: Freeman C. and Young A.: op cit p. 72.

Table 12.

PERCENT DISTRIBUTION OF FUNDS FOR PERFORMANCE OF RESEARCH AND DEVELOPMENT, BY INDUSTRY AND SOURCE, 1962.



Source: National Science Foundation, Reviews of Data on Research and Development, No. 40, NSF 63-37, September 1963 Washington, p. 4.

CHAPTER 5

RESEARCH, INNOVATION AND GROWTH : ASPECTS OF MEASUREMENT, AND SUGGESTED LINES OF STUDY

"All elements of our national economic growth are interdependent."

President John F. Kennedy.

5.1 BACKGROUND FOR ANALYSIS

For a general body of knowledge concerning the manner in which technological advances relate to economic growth, it is perhaps necessary to study the relationship at three levels:

(i) we need to know more about the introduction, impact, and diffusion of technical knowledge for the development of new products and processes at the level of the individual firms in a given industry, because many industrial advances result from the activity of these firms.

(ii) we need a detailed study of a number of major industries, emphasising the capacity of firms within the industries, and the industries themselves, to adopt new technologies, and analysing what motivates or hinders their advance. This method also opens the way to a study of various inter-industry relationships of certain technological changes.

(iii) the effect of technological change on the overall economy would illustrate not only inter-industry relationships but also how technological change promotes new industries and new sectors in the economy. For example, some older industries may be adversely effected if the new technological framework produces better and effectively competing substitutes; others may be positively stimulated if the changes provide an additional market.

Only when knowledge is available of the aggregate impact of technology on the entire economy, can a useful basis be provided for policy, particularly that relating to economic growth. The information provided under the above three broad types of study would be sufficiently detailed and complete, from the aggregate to the firm level, to allow for effective action programmes initiating, modifying, and accelerating technical progress.

The preceding chapters represent an attempt to arrive at a basis of study under the first head above, and, as such, represent a somewhat simplified description of the process by which a research achievement results in something of tangible benefit to the innovating form. They indicate that it may be possible to establish a definite relationship between scientific research and economic benefit by studying the process of scientific research leading to invention, thence to innovation and consequent economic growth.

5.2 SCIENTIFIC RESEARCH AND INNOVATION A RE-APPRAISAL

We have seen how innovation into the market place is frequently the ultimate objective of much research and development. Innovation, as used in economics, is dependent in no small measure on invention in a scientific sense (technical invention), and scientific discoveries are obviously determined to a large extent by the scientific effort devoted to inventive activity. The above type of innovation has been referred to as technological innovation and is the net result of a scientific discovery, its development in the laboratory, prototype and pilot plant stage, and its final commercial adoption and diffusion, the last mentioned being determined on the basis of certain conditions and factors being present in the innovating firm.

In short, it may be stated that innovative activity is a function of certain variables, some specified, and some as yet unspecified so that the parameters of this equation are unknown. The specified variables have been dealt with and represent the research and development input, the conditions necessary for innovation, and the factors affecting innovation.

The above is a summary of the "innovative process", and represents the theory descriptive of a possible research - economic growth relationship. Any theory, however, remains a rather vague concept until subject to some form of verification by empirical evidence. Consequently, the question arises whether it would be possible to attach measurable quantities to the above suggested relationship, and, in particular, whether one can quantify the economic effects of an innovation in a single firm, and, at the same time, establish, in quantitative terms, how far these effects can be attributed to research and development, or technological knowledge.

It must be remembered that it is not necessary for research to yield inventions to be able to contribute to economic growth. If, through research, existing industrial practices are developed to a degree where labour or capital is more efficiently employed, or materials more extensively utilized, the industrial output potential is increased and contribution is made to economic growth. In this way, strategically directed industrial research, undertaken in economically significant branches of industry, can yield regular and valuable contributions to the economy.

The above, however, does not depend on the 'chain of events' treated in this thesis; consequently, it does not give rise to a technological innovation and need not concern us here.

5.3 PROBLEMS IN MEASUREMENT

Appraisals of the business potential, or economic effects, of technological advances fall throughout a spectrum of uncertainty. The problem is to relate the time and cost of the research and development effort to the time and financial returns of commercial adoption. Where these elements are quite straight-forward and controllable, appraisal becomes a direct problem of economic evaluation. But many research and development activities do not fit this picture, and, particularly with radical technological breakthroughs, it becomes increasingly difficult to pin down the business significance of the innovation.

Difficulties of measurement arise because the value of a given innovation reflects not only the resources expended directly in its production, but also the resources expended in producing the prior knowledge on which it is based. The acute heterogenity of inputs, particularly of the inventive faculty itself, often excludes calculation. These problems can be clarified by briefly discussing the two main aspects of measurement, relating to output and those to inputs of the innovative process:

(i) Input Evaluation

The major difficulty encountered under this head is the extreme heterogenity of inputs which makes identification and evaluation an extremely involved task. The principal inputs to a research and development programme are specialised and trained direct labour (particularly qualified scientists and engineers), technical and managerial support staff, materials and equipment used for experimentation and the creation of test articles, and various other capital items (for example, libraries to facilitate information retrieval). These costs can be ascertained, for example on the basis of salaries and wages paid to research personnel in relation to time spent on the project, proportionate laboratory overheads, etc., and represent the alternative costs of these resources. Cost figures in money terms, however, often reveal little about the productivity factor involved, and in dealing with the input to research, it may be useful to go behind the money veil and measure physical volume, with allowance for quality differences. A further difficulty encountered in attempting to measure the inputs to research is that of determining when development activities cease and production begins. We have said that this is largely a matter of convention but one which has to be carefully considered for it would be erroneous to attribute the costs of establishing a factory for the purposes of manufacturing the innovation directly to research and development. Essentially, they are costs of production and should not enter the research production function. In particular one must be careful to isolate the costs of producing other products which do not relate to the innovation since they do not in any way affect the inputs to the innovative process. Similar costs which must be excluded are those relating to market surveys and promotional activities in connection with the new product that has resulted from the research.

This problem of definition for purposes of measurement is further intensified by the fact that there appears to be no unanimity on the subject of definitional concepts related to research and development.

(ii) Output Evaluation

Any attempt at measuring the output of the innovative process must take into account two main factors. The first is to measure the output of the research and development programme itself, and the second is to measure the output of the innovation. The problem is to reconcile these two so that the economic effects of the innovation can be legitimately weighed against its research input.

The output of a research and development program can be thought of as being in the form of a flow of instructions, each new set of instructions specifying inputs and operations to be performed in them, which when followed will result in a new product or process of specified attributes. They are the operational form of new production functions and the "payoff" to the programme can be regarded as the net value (discounted over time) of being able to employ these new production functions. It is generally agreed that it is not feasible to attach quantitative terms to the above. Instead a subjective evaluation is suggested, indicating to what extent the innovation incorporates all the output of the research programme.

The initial output of innovation, or its economic effects, can be readily ascertained, as was pointed out in the description of some of the more important effects of an innovation. In other words the effect of the innovation upon its initial introduction to production can be measured, for example by ascertaining its quantifiable impact on such factors as sales volume or revenues; its effect on savings in materials, labour and other costs, its effect on profits, etc. Some aspects of the effects of innovation are not possible to measure in this connection, for example those factors related to customer satisfaction and company prestige which again form the basis for subjective opinion.

Theoretically then, it would seem possible to measure innovation, but a word of warning is called for. Measurement frequently involves comparison over time, and, as J. Markham has put it:

"Innovation, or more precisely, the economic value of innovations, is not readily measureable. Even for simple cost-reducing innovations, the problem of measurement has not been satisfactorarily solved, and anyone who has followed the growing (and imposing) attempts at measuring quality-improving innovations is still left with that nagging feeling that a 1965 and a 1930 automobile not only perform the same functions differently, they also perform different functions. A comparison between the new and the old often is in part a matter of more or less, but in larger measure it is a matter of incomparable diffrences. And for truly new products, there is no appropriate analogy to be found in the preceding time period."[1)]

It would appear then that even this aspect of measurement is not entirely free of some form of subjective interpretation, particularly in the case of more radical technological advances. But, granted the feasibility of such measurement in

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1. Markham, J. "The Joint Effect of Antitrust and Patent Laws upon Innovation," American Economic Review, Papers and Proceedings, Volume LVI, May, 1966

many instances, the question arises as to what extent the measured effects of innovation are dependent on the measured research and development programme, and it is precisely here where the main problem of measurement arises.

5.4 THE MEASURE OF DEPENDENCE

Assuming that the costs of innovation (in terms of the inputs to the research and development programme) have been measured on the one hand, and the economic impact of the innovation on the other, can we obtain an accurate measure of the degree of dependence involved? In other words, if the benefits from the innovation (in terms of increased sales or profits, or decreased costs) exceed the costs of the research and development programme, can we assume that an empirically verified, and positive, relationship exists between research and growth. I am forced to the inescapable conclusion that the answer is negative.

It simply is not possible to set up a general production function from which a cost function for the production of technological knowledge in relation to its economic use can be derived because of the existence of three main factors:

(i) the input-output relationships cannot be strictly quantified in every case,
(ii) the factors of production exhibit extraordinary heterogenity, and
(iii) the production of new technological knowledge involves great uncertainty.

We have seen that the chief influencing factors making for successful innovation are, inter alia, the technical basis of a firm (that is, the technological knowledge necessary to manufacture a firm's current products), the size of the firm, its managerial and labour talent, and the character (technical) of the firm.

The main problem then in establishing a formula for evaluating research results is that of distinguishing the contribution of the research and development base underlying the innovation from the contribution of other activities in the firm. Unfortunately this proves to be an impossible task in many instances because of the various factors involved, and one frequently encounters arguments such as the following:

...."without the sales force, your new products would still be sitting on the shelf."
...."with the energy devoted by manufacturing to getting this new process going properly, we could have turned out millions of items by the old process, at a good profit."

The difference between success and failure is often not the merit of the research funds, but the crucial aspect of research application, with its complex of influencing factors such as the shortage of creative research and development management. Unfortunately it is not possible to objectively measure the contribution of these other factors which must always remain the subject of personal evaluation to a greater or lesser extent.

There may well be some relationship between the cost of research inputs and the improvements in economic performance resulting from technological change, but it clearly is not a simple one. Above all, it is not one readily subject to quantitative analysis free from subjective evaluation. Thus the necessary proportion of research costs in total costs to obtain a particular rate of technological advance - and hence the costs of research inputs to improvements - will vary with a number of factors such as : the technology in use in the firm in the initial period, the extent to which the firm is equipped to appreciate the possibility of increased sales and profits inherent in the innovation, the availability of labour skills, etc.

A satisfactory quantitative, or mathematical, analysis would have to weigh the effect of these factors on the required level of the various non-research or complementary costs, as well as the possible relationships between these complementary inputs and the research input. It is hardly surprising then that no-one has yet succeeded in formulating such a model.

5.5 BLUEPRINT FOR MEASUREMENT

The author is currently engaged on a personal interest study arising from his activities in the project of research economics currently being undertaken by the Industrial Economics Division of the Council for Scientific and Industrial Research. The investigation is proceeding along much the same lines as similar overseas studies and is aimed at quantitatively analysing the process of research to invention to innovation and possible economic benefit at the firm, or micro-economic level. Unfortunately the analysis is subject to much the same difficulties as outlined above, in that a neat quantitative solution is not forthcoming without subjective evaluations and personal opinion creeping into the picture.

The methodology of study has been to select certain South African firms which have been identified with the above innovative process and to approach them for information along the lines of the memorandum outlined below:

5.6 MEMORANDUM OF A PROPOSED CASE STUDY ON THE RELATIONSHIP BETWEEN SCIENTIFIC RESEARCH AND ECONOMIC GROWTH

It is proposed to make a detailed investigation (based on the pattern established by overseas case studies) of the chain of events by which a research project leads to technical invention, is developed, and introduced as a commercial innovation, and if possible, to evaluate its effect on the growth of the relevant firm or industry. The study envisaged will trace the development of the original research project to the final process or product used by the firm or industry through the following phases:

1. The research stage

   The research may have been fundamental research, namely research undertaken for the advancement of scientific knowledge without a specific practical application in view, or applied research, namely research undertaken primarily for the advancement of scientific knowledge with a specific practical aim in view. The applied research phase may also demonstrate the potential utility of the research through the use of bench-scale apparatus.

2. The development stage

   Development activities reduce the knowledge to practice in a workable prototype form and development work begins when an invention (the application of scientific knowledge to the industrial objectives of physically developing new products, techniques and processes), having been shown to "work", has been chosen for application. This phase usually involves the technical problems of adjustment, pilot operations, and the construction of prototypes.

3. Engineering or adoption phase

   Engineering or adoption activities refine the process or product for commercial exploitation. It is here that the activities of the previous phase permit extended operations once they have proved successful. The invention is now converted into an innovation, generally defined as the application of technical change to economic activity by the placing of a new product on the market or the introduction of new and improved processes into production.

4. Operations phase

   Operations activities, in the form of production and sales, put the new technology into final use. Often improvements to, and modifications of the process or product are undertaken during this phase. (Although, of course, such improvements and modifications may continually be carried out).

The above four phases are frequently grouped together under the heading "technical progress", which involves a description of an idea from its first discernible beginnings to its successful commercial use. A comprehensive analysis of the above phases, with the specific intention of evaluating the economic impact of the project will call for the following type of information.

A. An historical background, which will merely comprise descriptive information, illustrating the progress of research to development to the final process or product used by the firm. This will include technical information on the various stages, regardless of where they were performed.

B. An analysis of costs. Ideally, cost figures are required for three distinct phases of the above process:

(i) Cost data on the research project itself and its subsequent development up to phase (4) in the above listed chain of events. Costs envisaged here are those which will give a comprehensive figure for the cost of all research, development and engineering work involved in bringing the idea to its final form in use by the relevant firm. This will include research and development activities undertaken both at the research institute and in the firm. Such costs will include, e.g., salaries and wages of personnel working on the project (the actual pro rata compensation paid to the research personnel working directly on the particular project); a further percentage of this amount as a fair share of the cost of the auxiliary research service personnel, and of gas, electricity, maintenance of laboratories, depreciation and similar overhead and operational costs; the cost of materials, proto-types, apparatus and equipment and the costs of additional training of personnel.

(ii) On the same basis, any subsequent costs of further development or improvement carried out by either the firm or the laboratory up to the present stage of production.

(iii) Those costs incurred for the initial introduction of the new process or product into the firm's production schedule.

C. An analysis of the economic effects of the research

(i) An analysis of the growth of the firm. The data required here are to be used in evaluating what effect the research has had on the firm or industry which introduces the new process or product in its production schedule. All benefits, savings and revenues attributable to the use of that innovation are to be taken into consideration. For example, figures on the effect of the new process on labour and materials inputs, time savings, consequent cost reductions; its effect on selling prices, market extension, and export performance would be of relevance here. A brief synopsis of the relevant firm - its history, nature, size and function - would also be desirable.

(ii) Data on wages, interest, rent and profits

The wages, interest, rent and profit of the firm reflect the contribution that the firm makes to the Gross National Product, and thus reflect the performance of the firm in the wider economic context. If it is possible to measure the contribution (derived solely from the use of the new process or product) of the firm to these four categories, figures should be provided on an annual basis, covering the period from when the new process was first introduced up to the present date.

5.7 AIMS AND METHODOLOGY OF ANALYSIS

The above memorandum is designed to act as a guide for the receiving firm as to the provision of data on the innovative process. In the first place,it must be pointed out that the firm need not have carried out its own research work. The firm in which the innovation was incorporated into the production schedule forms the focal point of the study, and, as we have seen, need not base its innovation on an internal research programme. In fact, two out of the three firms approached for the study based their technological advances on research and development activities conducted outside the relevant firm, on the "importation" of technological know-how, and confined their activities to development and engineering activities for purposes of refinement, production, and improvement of the advance. Secondly, although the three firms approached admittedly are illustrations of "success stories," (in that the adoption of the innovation and its consequent use in production proved successful in terms of economic benefit) it is also intended to select certain research discoveries which have eventuated in an unfruitful innovation (in terms of an economic loss or a scrapping of the innovation). In the latter case, an attempt will be made to identify the cause of failure, whether inherent in the nature of the research discoveries or in the innovation itself or in the absence of certain factors essential to successful innovation. Having pinpointed the proximate cause(s) of "unproductive research", a further attempt will be made to gauge the extent or measure of its unproductiveness. Finally, the study is intended to embrace the two main categories of technical innovation: an innovation resulting in a new product, and a process innovation; and the firms approached have accordingly been selected to illustrate the two different types of innovation.

Bearing the above in mind, I would like to outline briefly what the methodology of study as summarised in the memorandum above seeks to achieve. It can be seen that the first section embraces rigorous definitions of the various phases of activity encountered in the innovative process. The lack of unanimity on definitional concepts has been mentioned and this section (under points 1, 2, 3, and 4) is intended to resolve the matter so that businessmen, in assigning cash values to research and innovative activities, will have a clearer idea of what is required. Uniform definitions, if accepted, have the added advantage that they enable inter-firm comparisons of the quantitative data attached to them, and thus can provide the basis for a more extensive study of the innovative process at the industry level. The major purpose for the inclusion of definitional concepts is, however, to firstly identify the correct inputs to the innovative process so that the relevant firm can calculate the appropriate research and development costs, and secondly, to demarcate clearly the different stages of the "chain of events." When calculated in this fashion, an estimate of importance (in terms of costs) of the various activities will be obtained.

On the basis of the above definitions, section B of the memorandum requires an analysis of costs from the respondent. It will be noted that the costs required are not limited only to research and development activities conducted prior to innovation but, in addition, incorporate subsidiary costs relating to introduction of the innovation to the firm's production schedule as well as any post innovative research and development costs incurred for the purposes of refining the product. These latter costs are extremely important when one considers that the greatest economic benefits to innovation have often resulted from improvements carried out on the product or process after production is set up, for example through adapting the product to specific customer preferences, or through taking advantage of latent economies of scale. Of course it is more difficult to attempt cost calculations in the improvements stage because of the complexity involved in distinguishing the research and development costs from normal costs of production; however, these additional costs attributable to the innovative process must be considered. Furthermore, should additional research and development activities for improvement purposes be undertaken outside the firm, as is often the case, these costs should also be taken into account.

Information provided on the basis of the above section then will provide comprehensive cost data on the entire innovative process : the conception of the idea as a scientific discovery, its development in the laboratory and pilot plant stage (to the form of technical invention); further development and engineering activities aimed at refining the invention for production purposes; adoption (by means of operations activities) to production (in the form of actual innovation); and finally, post innovative research and development costs aimed at improving the innovation or adapting it to large scale production in order to experience economies of scale.

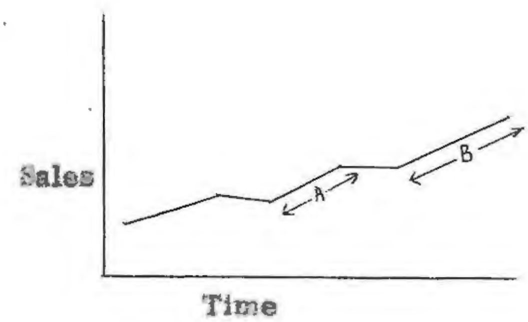
Section C of the memorandum, "An analysis of the economic effects of research," is designed to obtain data on the economic value of the innovation. In its present form, the section is subdivided into two parts, the first part to quantify the value of a process innovation and the second to estimate the value of a product innovation.

It can be seen that the former concentrates specifically on the cost schedule of the firm over two different periods of time: the pre-innovation period and the post-innovation period. In other words,the methodology adopted here seeks to uncover cost differences, or the cost reductions obtained in production,by employing a new or improved technique of production in the form of a technological process innovation.

The latter requires data on wages, interest, rent and profits attributable to the innovation and as such concentrates on a product innovation. Adequate data here will measure the growth of the firm (as well as reflect its performance in the wider national context) which has resulted from the production of a new or improved product by the firm.

The above then is a brief outline of the method of study used and, since the study requires data up to the present stage of production of the firm, it should present a comprehensive statistical picture of costs of inputs and economic benefits.

Unfortunately, it has not proved possible to include the results of this study in the present analysis because respondents are still busy compiling data. Preliminary estimates which have been returned, however, indicate that the study should be successful, and serve further to illustrate certain aspects of the theory set out in earlier chapters. For example, sales and profit data received from one firm show marked increases roughly corresponding to periods of post-innovative development and research expenditures. In other words, research and development activities aimed at improving the original innovation have resulted in new models of the product favourably affecting sales and profits:



A and B reflect periods following on research and development activities concerned with improvement of the initial innovation.

First impressions of the methodology of study therefore appear to be favourable in that it should provide an adequate statistical background of direct costs to the innovative process and the benefits resulting therefrom. However, I must point out that the question of indirect costs has not as yet been satisfactorarily resolved. Thus, although at this stage one will be able to measure the research and development and subsequent engineering and operation inputs to the innovative process, and the economic benefits consequent upon innovation, one cannot measure the effect of the other factors influencing the innovation, and therefore it cannot be established to what extent the economic benefits to the innovation have been dependent on research and development. To establish quantitatively the relationship between research and economic growth via innovation one must be able to do this.

To date no specific plan of study has been decided upon in this connection but the author envisages the following: that the first memorandum should be followed up by subsequent questionairres, or personal discussions witht the relevant firm aimed at uncovering the extent of influence exerted by these other factors such as labour and managerial talents, investment, market characteristics, etc. It is realized that this phase of the study will be dependent to a large extent on the personal evaluation and opinion of the manager or other party supplying the information, but,as we have said, the method of this type of study cannot at present be entirely free of the subjective element. What is hoped for, however, is that the respondent will be able to assign some weight or index of importance to the non-research inputs to the innovative process in relation to the firm's total cost schedule, and,in this way,it may prove possible to seperate the contribution of research and development inputs from other inputs. If this can be done, and prima facie it seems feasible, it will be possible to subject the proposed relationship between scientific research and economic growth to some form of empirical test. A lot more thinking is required,however,before any definite promise of success can be made.

5.8 CONCLUDING REMARKS

The difficulties of measurement and the variety of factors influencing and affected by successful innovation serve to illustrate that to view research and development as a single cause of economic growth is to oversimplify complex economic relations. Furthermore,there is no certainty that the potential contributions of scientific research and development will be realised or that technological advance,in the form of (successful) innovation,must follow the scientific research and development.

We have seen that to many people, a great scientific and technological revolution means a host of marvellous discoveries and inventions. What the truly revolutionary change really implies is <u>the immediate and direct introduction of science into economic processes in a systematic and efficient manner</u>. Research and development is not "all powerful", and the actual adoption of technological innovation depends on such factors as commercial use and application, competitive pressures, profit possibilities, business-cycle fluctuations, and numerous other non-research activities, which are difficult to measure, and even to identify. Successful identifications have indicated that co-operation is essential, for example:

"In a recital of major improvements in the rayon process ..... teamwork between research and production men, with an understanding administrative management, led to a successful industrial development" 1)

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1. Hollander, S: <u>The Sources of Increased Efficiency : A Study of Du Pont Rayon Plants,</u> MIT, Cambridge, Massachusetts, 1965.

That is why all aspects of research - basic research, applied research, and, in particular, development and engineering for production activities - are of such fundamental importance. Indications are that a firm, an industry, or a country's competitive advantage will depend, less on the lowering of costs, less on sources of supply of resources, and less on conditions in the capital market, but more on its power to be an innovator in research and technology. This has been the reason for the inclusion of the final chapter on the South African research scene to give an idea of the research and technological potential available for development and subsequent application in the Republic.

CHAPTER 6

RESEARCH IN SOUTH AFRICA

1900-1965

> "..... what is new in our time is the multiplication of innovations - and the widespread recognition and systematic application by industry of the notion that new products and new processes are the key to a company's growth, an industry's growth, a nation's growth - and the recognition that, through systematically planned and administered research, we can count on the continuous development of innovations to keep the economic system expanding."
>
> Leonard S. Silk. [1)]

6.1 INTRODUCTION

Sixty years ago the world was poised on the brink of a new era in science - an era of progress unprecedented in the history of mankind. In South Africa, the people were only just recovering from the effects of a tragic war and, in addition, the economy was suffering the plight of the dreaded cattle disease, rinderpest, which in 1896 had stretched from the Transvaal to the Cape, leaving behind a scene of utter desolation, with 95 per cent of all domestic cattle dead and whole herds of game exterminated. A few years later it could be said of South Africa, that:

> "..... in 1906, a nation hungry for knowledge, impatient for development, bursting with energy and poised for progress. Yet, also a nation waiting for the men who would shape its destiny, and challenge with science the multitudes of problems which must be solved before people can prosper." [2)]

South Africa has prospered admirably, and that despite the many problems in the nature of the land - a land of more than 472,550 square miles, roughly five times the area of the United Kingdom, and presenting the observer with a view of many and varied contrasts. These contrasts range from the climatological to the geographic. But perhaps one of the most important and problemmatic aspects of life in South Africa has been the multiracial character of her population. In 1964, this population

1. Editor, Business Week
2. Pioneers of the Modern South Africa, The Sunday Times, 26th June, 1966, Johannesburg. p. 10.

included over 14 million non-whites, the main groups being Bantu, Asiatics and Coloureds and approximately 3.3 million whites. The multiracial groups of the population differ vastly in backgrounds, culture and general way of life.

6.2 INDUSTRIAL DEVELOPMENT AND SCIENTIFIC CHANGE

In most countries, the development of industrialization has brought in its train problems such as overcrowding in urban slums and the attendant evils of malnutrition and deficiency diseases, pollution of the atmosphere and of water supplies, traffic congestion and social maladjustments caused by the combination of these circumstances. In her drive towards industrialization, South Africa has proved no exception. She has suffered her fair share of the above problems and these have been magnified manifold by the difficulties engendered by a multiracial community sharing the same land and resources.

Despite these problems and the complications arising from the multiracial nature of our population, the economy of the Republic has undergone an almost unprecedented rate of development over the past 70 years. In the last two to three decades, the predominantly agricultural and mining economy of South Africa has evolved into a technological, industrial economy based on the country's rich agricultural and mineral resources.

We have seen that no technologically progressive country can exist as such without the application of new knowledge to technological change. These concepts are included in the nature and definition of such a country.

In the start, when the beginnings of a technology-based economic society were taking place, research and innovational change in South Africa had been founded, in large measure, in knowledge and experience imported from overseas, particularly from Europe and America, the areas of major scientific endeavour. This is of particular notice when the rapid development of the mining industry is considered, a development based on the knowledge embodied in labour, equipment and methods imported from overseas. However, the mining industry was not the only sector of the economy to benefit from increased knowledge; agriculture underwent a transformation to more modern farming methods, and the S.A. manufacturing industry forged ahead.

As has been the experience in most countries, the development of industry has accelerated tremendously since 1940, and this has been accompanied by a corresponding development of science and scientific research. With the phenomenal growth of industry, a rapid urbanization of the Bantu has been in progress and the responsibility for their education, scientific and technical development has lain mainly with the European section of the population.

No country, we have seen, can afford to remain dependent on overseas knowledge, particularly the more advanced it becomes technologically, and particularly where the circumstances prevailing in the developing country differ so markedly to those in the other countries, and moreover:

> "The scientific problems facing the countries of Africa are in many ways greater and more urgent and more challenging than those to be found anywhere else in the world. In view of the unique character of our problems, the advice which we need will not, however, come in any large measure from the study or the application of existing knowledge. It will have to be based upon special investigations carried out in Africa by men gifted in the solution of new problems and whose original minds can devise new methods of attack on old problems. In other words, it will demand much fundamental or basic research." [1]

6.3 THE DEVELOPMENT OF SOUTH AFRICAN SCIENCE TO 1945.

Scientific research has accordingly developed in South Africa, as in most other countries, as a result of necessity, until today when much technological and innovational change has been brought about by basic and applied research conducted in the Republic itself, particularly in the spheres of activity which are the responsibility of government and local authorities. As an illustration of the role played by technological change in S.A. growth, Dr. T.A. du Plessis [2] assigns the following shares in South African growth from 1946/7 to 1956/57 to four causal factors:

Import Substitution	41%
Final Domestic Demand	30%
Technological change	16%
Exports	13%

1. Naudé, Dr. S.M. Science and Government : A Problem of the Present Age in an address to the S.A. Parliamentary Scientific Society, Cape Town, 30.4.1960.
2. Dr. T.A. du Plessis, The Industrial Growth Pattern and the Real Forces of Expansion in South Africa, 1946/7 - 1956/57, unpublished D. Com. thesis, University of South Africa, 1965, p. 190.

"It is important, therefore, to look not only for the statesmen and capitalists in South Africa at the turn of the century, but also for the scientists - the men whose genius was responsible for reshaping a crippled nation until it emerged as the most advanced of any south of the Sahara. We find them in 1905 at Kimberley attending the fourth congress of the South African Association for the Advancement of Science, founded in 1903 to set forth the claims of science to the sympathy and support of every citizen and every government of a civilized community." and where

it was stated...... "Who is there among us who can foretell what this country will be like 20 years hence? We have millions upon millions of tons of coal, iron and limestone lying side by side ..... we must dream dreams." 1)

And the dreams materialized. But this is not to presume that organized research sprang into being as it were. In the older industrially developed countries, it is generally agreed that organized industrial research, conducted by scientists and engineers is a recent development of the past 40 odd years. This seems hard to appreciate when we consider the phenomenal growth of the research and development "industry". America alone has some 100 independent research institutes. The independent research institutes in Western Europe, with special responsibilities for industrial research, financed wholly or in part from government funds, also largely date from about 1920.

The first organized research institution in South Africa, the South African Council forIIndustrial Research, was established on October 5th, 1945, by an act of Parliament and the passing of this Bill marked a turning point in the history of Science in South Africa.

Up to that time, the growth of indigenous science had been spasmodic. Schools of research and development had centred around gifted individuals, but these gradually disappeared when the leaders departed (a common occurrence in any developing society). Fortunately important exceptions were provided in some fields, and the development and furtherance of research in these spheres can be attributed partly to social and economic needs and also to the unrivalled opportunities for research in these particular fields - but perhaps most of all to the outstanding individuals who appeared at the right moment.

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1. Pioneers of the Modern South Africa, The Sunday Times, Johannesburg, op. cit. p. 11.

One of these was Arnold Theiler who founded an institution, Onderstepoort,which was to become world famous for its contributions to veterinary science. Today, countries in Africa north of the Limpopo depend on its production of vaccines to combat the animal diseases of an emergent continent, and,insodoing,Onderstepoort has been instrumental in the opening up of vast tracks of sub-tropical and tropical Africa to animal husbandry and consequent socio-economic gain.

The influence of Theiler extended well beyond the sphere of veterinary science and it has been said by some authorities that it was his work which inspired the establishment of the South African Institute for Medical Research in 1912. With Onderstepoort showing the way in animal research, it was only natural that a similar institution should be founded to prevent and treat human diseases. South Africa is a country with many medical problems dictated by varying climates; influenced by a multitude of peoples living in conditions stretching from the most primitive to the most luxurious; aggravated by a variety of diets, and diseases. The founding of the Institute under Dr. W. Watkins-Pitchford was a start to combat these problems, and a long way has been travelled since with the performance of valuable work in poliomyelitis, pneumoconiosis, tubercolosis, bilharzia, and the more recent triumph of a vaccine against trachoma. The impetus provided by the Institute has encouraged research in nutrition, pathology, genetics, virology, bacteriology, radiotherapy and chemotherapy.

The important role which South Africa has played in astronomy can be attributed to its accessibility to Europe and to the clear skies which present unrivalled opportunities for study of the Southern Firmament. From the humble beginnings of the work of Robert Thorburn Ayton Innes, South Africa now possesses four main observatories - the Republic Observatory (Johannesburg), the Royal Observatory (Cape Town), the Radcliffe Observatory (Pretoria) and the Boyden Observatory (Bloemfontein).

Geological research developed as a natural consequence of the discovery of diamonds and gold,and the scientific study of geological formations uncovered a bountiful store of mineral wealth. Geological research, in conjunction with imported knowledge and skill on mining techniques,has been a major factor making for the outstanding progress of the mining industry as a major sector of the South African economy.

The luxuriant and varied flora and fauna of South Africa has long attracted botanists, biologists and collectors from all over the world. In addition, today in South Africa there are four national museums and a number of provincial and local museums making just under thirty in all and a start has been made on the building of a national science museum in Pretoria. The main official organization which is charged with the study of the natural vegetation is the Botanical Research Institute of the Department of Agricultural Technical Services. South Africa has also proved the leader in conservation of wild life in Africa, providing ample opportunities for study in this field, which today is receiving closer attention.

Thus it can be seen that the pre 1910 years in the South African science era were characterized by the prominence of individuals of outstanding ability who gathered schools of research under them. Gradually this notion of science in the Republic gave way to a type of organized research under government auspices, not in accordance with any preconceived plan, but, as noted, dictated by necessity and convenience alone.

For example, veterinary research and field services were developed under the Department of Agriculture which also developed a comprehensive range of divisions responsible for all aspects of agricultural research as well as services such as grading of produce, quarantine and education policies, conservation and extension. The Department of Forestry too has made a notable contribution to the economy through its rigorous afforestation policy. The Geological Survey fell under the Department of Mines, and the Department of Water Affairs was given the major responsibility for water resources.

It can be seen that research was being administered under the Public Services System of Administration, generally recognized as not being the most flexible and ideal machinery for all kinds of research. Consequently, the South African Institute for Medical Research was established by the Mining Industry with government support in 1912. This was followed 20 years later by the fuel Research Institute in 1932, financed with a levy on coal owners and a pro rata subscription from the Government.

These are the broad, general outlines of the scientific scene into which the C S I R was born in 1945. However, before going on to discuss the C S I R itself, a few words on research by industry and the facilities for training scientists in South Africa are called for.

6.4 RESEARCH BY INDUSTRY

In any developing country there is a pre-eminence of foreign-owned/administered subsidiaries. In the early stages of South African industrialization there was an almost complete dependence for research upon the laboratories of overseas principals and this dependent attitude has persisted in many instances. However, the position has changed rapidly in recent years and almost all the larger manufacturing establishments now either have, or are in the process of building up, their own research facilities.

The largest industrial research laboratory in South Africa is that of African Explosives and Chemical Industries. Until 1952, its Research Department was a small unit intended to provide a service to the Company's production departments in the solution of ad hoc manufacturing problems. Since that time, however, the department has undergone a controlled expansion, involving the expenditure of thousands of rands in the construction and equipping of new laboratories and workshops, a considerable increase in staff, and the initiation of long term research aimed at providing background knowledge to the company's manufacturing interests.

Worthy of mention also are the research activities of the South African Iron and Steel Corporation. Iscor has constructed and equipped research laboratories of considerable size to serve both its own needs and those of a number of associated companies. It has unfortunately not proved possible to obtain details of further industrial research conducted in South Africa. Suffice it to say that there appears to be a growing awareness amongst South African industrialists of the importance of "home-grown" research activities, and during the past 20 years, no less than 40 major firms have established their own research laboratories in South Africa.

6.5 TRAINING OF SCIENTISTS IN SOUTH AFRICA

The position regarding the supply of scientific and technical personnel in South Africa was a cause of considerable concern up to the 1940's, and is still a major problem today.

Although the training of laboratory technicians was begun in technical colleges at a fairly early stage, professional training in science was only available at the universities. However, the output of graduates trained in research was relatively small and these number s were further decreased by the fact that a significant proportion of them went overseas for a final broadening of their training and experience. Many of them did not return. Furthermore, the needs of a rapidly developing industry also tended to lure science students away from the universities prior to the post-graduate research level. Research facilities at the universities themselves were poorly inadequate in relation to the needs for them well into the 1940's when the C S I R made its appearance and lent considerable strength to university research requirements.

The situation was further aggravated by the unsatisfactory position in regard to the teaching of science in the schools, resulting in part from the decreased interest in science teaching as a profession (following on the demands for scientists in industry), and from the inadequate rates of pay for science teachers. Superimposed on all these difficulties is the fact that South Africa has relied on the recruitment of her scientific manpower from only one (a minor) section of the population.

The above is a brief description of the serious obstacles preventing the optimum use of perhaps our most vital resource - "human capital", and one is tempted to conclude that the position is changing and a solution is coming about. Happily the position is changing, due mainly to the cognizance of science as a profession and, on an increasing scale, to the economic importance attributed to science. But more is needed, and rapidly too.

Dr. van Zyl has said: "The possibilities for growth and development are tremendous. The raw materials are there, but we need the men and women to do the work - men and women who are scientifically and technologically literate.

While, naturally, we do our utmost to attract more scientists, technicians and skilled workers from overseas, it is obvious that the main solution to our problem lies in the optimum utilization of our existing manpower - and that means 'woman power' too". [1)]
It has been estimated that 6 years ago, South Africa lacked 500,000 technical, professional and kindred workers, and the demand for such personnel continues to run ahead of the supply - the costs of progress in terms of 'technical' manpower run high indeed.

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1. Principal of the Pretoria Technical College, <u>Sunday Times</u>, Johannesburg, June 26, 1966.

The Strassacker Commission has recommended two proposals to meet the demand - that women should be attracted to engineering as a career and that Africansbe re-admitted to the universities closed against them in 1959. Both these proposals are acceptable in principle, but neither promises much relief in the short run.

The root of the trouble appears to be grounded in the schools, in the lack of adequate (and competent) mathematics and science teachers, and to overcome this a considerable change in our national scale of priorities is urgently required. A better system of education in science and technology must be built up, and the wider this system extends, the more promising the results.

6.6 THE SOUTH AFRICAN COUNCIL FOR SCIENTIFIC AND INDUSTRIAL RESEARCH

6.6.1 INTRODUCTION

A brief introductory note on the establishment and structure of the British Department for Scientific and Industrial Research (D S I R) serves to introduce the South African scene.

One of the reasons leading to the establishment of the D S I R in 1916 was the widespread cognizance, particularly during the First World War, that, whereas much of Britain's industrial strength lay with the smaller firms, the costs of research are such that the setting up and operation of an effective research department was beyond their reach. The objects of D S I R are to promote and organize scientific research with a view especially to its application to trade and industry. DSIR has become industry's link with scientific research:

> "Through D S I R, the small manufacturer can have all the resources of organized science brought to bear on his own particular problems. Whether he wants to bend plywood or to cut down smoke from his factory chimney or destroy beetles in his warehouse, D S I R can help him." 1)

More often than not, the answer to such a technical problem will already be known, and D S I R plays its part by putting the manufacturer in touch with the information he needs. If research is called for, D S I R may provide the necessary facilities through its own specialized laboratories. The Department also employs a system of technologically orientated research associations, but, although these research

1. D.S I R Research at your Service, H M S O, London, 1954. p. 1

associations can cope with the research needs of specific industries, modern industrial practice also requires research of a more general character. For this purpose D S I R maintains 14 laboratories of its own in such fields and these laboratories exist for the benefit of the community as a whole. Lastly, the D S I R maintains a technical services division (TI) which puts inquirers in touch with specialized sources of scientific and technical information, and answers queries for which no specialized sources exist.

The U.S.A., Canada, Australia, India, New Zealand, and South Africa with the C S I R, inter alia, all have national research bodies which provide basic scientific services through national research laboratories. In fact, the development and structure of the South African C S I R is strikingly similar to that of the D S I R in Britain.

The principle that government should support scientific research, because, in the long run, it is the state, or rather the general public, that benefits, is one that became apparant during the world wars and brought an increasing awareness of the importance of research to most countries. Economic theory too has served to heighten the interest in research as a growth promoting factor.

In line with these general trends, the South African Government set up the machinery for providing the country with organized science by the establishment of the C S I R in 1945.

We must pause a moment to reflect upon the characteristics of the stage of industrial development prevailing in South Africa at the time of establishment of the C S I R. These characteristics in turn reflect upon many of the characteristics of research conducted both by the C S I R and by other non-industrial research organizations. In the first instance, South African industry was a "bustling infant" in the growth family - whereas South Africa had been engaged in an industrial revolution of a mere 20 years previously, most of the industrialized Western countries were well advanced into the technological revolution. The obvious result to follow from this is that much of the research conducted overseas lay in, and, more especially, was applicable to, the conditions and environment peculiar to that country and, as such, was not directly applicable to the South African scene.

Secondly, since South Africa was a relative newcomer to the growth scene (and, by definition, the technology - research scene) research undertaken for its own sake would involve, in a variety of instances, duplication of existing exogenous research.

Thus, what was called for in many cases was not simply research, but "research into research" or research aimed at the adaptation of overseas efforts to local conditions - research into "imported technological know-how." In particular, research was needed into the basic properties of South African natural resources.

The above then are the broad general outlines of the scientific scene into which the C S I R was born in 1945. Agricultural and veterinary research as well as geological research were specifically excluded from its terms of reference. So also was research in the social sciences (with the exception of personnel research) and the humanities, for which a seperate National Council for Social Research was created under the Department of Education Arts and Science.

6.6.2 The Structure and Research Activities of the C S I R

The objects of the C S I R as stated in the Scientific Research Council Act of 1945, as amended, are set out below:

(a) to promote the utilization of the natural resources of the Republic and the productive capacity of its population;

(b) to seek new knowledge through research investigations and tests in such a manner as it may deem desirable, mainly with the object of improving technical processes, methods and services and industrial products, and of developing processes and methods which may promote the expansion of existing, or the establishment of new industries or the better utilization of raw materials and waste products;

(c) to undertake or aid scientific research in connection with such matters as the Minister may refer to it for investigation;

(d) to provide and control facilities for the testing and calibration of precision instruments, gauges, and apparatus, the determination of their degree of accuracy and the issue of certificates in regard thereto;

(e) to provide and control facilities for research in connection with standardization in industry and commerce;

(f) to maintain primary scientific standards of physical quantities for the Republic and to provide for their comparison with international standards from time to time;

(g) to foster the training of research workers and to establish and award research bursaries;

(h) to encourage and promote scientific research generally, and to contribute thereto financially;

(i) to foster, recognize and aid the establishment of associations of persons engaged in industry for the purpose of carrying out scientific industrial research, and to co-operate with, and, subject to the conditions approved by the Minister, make grants to such established or recognized associations;

(j) to establish and control facilities for the collection and dissemination of information in connection with scientific and technical matters;

(k) to act as a liaison between the Republic and other countries in matters relating to scientific and industrial research;

To meet these responsibilities,the C S I R was formed as a corporate body outside the government service, thereby having the flexibility which is regarded as essential for the effective development of research activities. The C S I R is equipped with thirteen national laboratories and institutes, in each of which a Director takes charge of the organization and co-ordination of research, and in addition, it controls several research units and other services. Among its total staff of more than 2,000 are approximately 500 scientists and 1,000 technical officers and technicians. These staff the various laboratories and institutes for research into fields such as astronomy, building, chemistry, defence, the mathematical sciences, mechanical engineering, nutrition, physics, personnel problems, roads, telecommunications, water, timber, and wool textiles. They also serve in the specialized supporting services required for the proper functioning of the C S I R.

According to Dr. S.M. Naudé [1) .....]"the C S I R has been guided by two basic principles. Firstly, the C S I R, as a scientific body, has steadfastly endeavoured to adhere to the traditions of the scientific profession. Secondly, the C S I R has

1. Dr. S.M. Naudé, President, S.A.C.S.I.R., op. cit. p. 3

consistantly regarded industrial research as primarily a responsibility of industry itself and has used all the means at its disposal to encourage and induce industry to engage in research in its own interest ......"

From the above two principles and from the objects of the C S I R set out above it can be observed that the aims and activities of the C S I R can be divided into two broad general fields. These are firstly, the development of science itself, and secondly, the development of science - research and technical services - for industry. These two distinct, but closely related, divisions will be briefly described below.

A. The development of science

Briefly, the C S I R achieves its objects in this sphere by the support of research projects at the universities and museums, through basic research programmes conducted in its own laboratories and institutes, and by the development of scientific library and information services. The Council is also responsible for medical research.

An immediate and pressing problem confronting the newly formed Council was the lack of adequate research facilities in the universities. To overcome this problem, a system of senior bursaries or fellowships and postgraduate bursaries, coupled with grants for running expenses and major equipment was introduced. Recently this scheme has been extended to include support for research units.

In developing its research activities, the C S I R also does everything possible to make the most use of what is being done elsewhere. The C S I R, on its establishment, took over the responsibility for the South African membership of the International Council of Scientific Unions and its affiliated unions. The C S I R further maintains scientific liaison offices overseas to keep in touch with latest developments there and, wherever possible, members of staff are sent overseas for further training and experience in the latest scientific techniques and their application. This is important since it is generally acknowledged today that participation in international scientific programmes is to the mutual advantage of all participants. In this way, South African scientists can keep abreast of the latest developments in specific fields while South Africa, with the knowledge acquired here, and its unique geographical position, can make valuable contributions to the advancement of knowledge in other fields. Moreover, such participation serves as a stimulus to the development of indigenous South African science.

In the field of medical research, the C S I R has followed much the same principle used in the universities' research support. To explore and develope medical research,the C S I R has not established separate medical research bodies, but by giving its support to about 25 research units, groups and projects, the Council has ensured the continuous progress of research under the leadership of eminent research workers in fields considered to be of particular importance for South Africa. These activities are carried out in medical schools, teaching hospitals, universities and other medical institutions throughout the country.

The above then is a brief picture of the activities of the C S I R in the field of science development as such - basic or orientated basic research - and a prominent characteristic of much of the scientific research conducted at the C S I R is that it falls into the category of what we have labelled in an earlier section - "research in the public sector." To understand this more fully, we must repeat some earlier comments made about the general economic climate prevailing at the time of establishing the C S I R. In the first instance most manufacturing industries in South Africa had not yet reached that advanced stage in technological development where the application of research was a primary consideration. The new industries springing up were concerned with the problems of introducing established industrial processes into an unfamiliar environment. As a natural consequence,the main lines of C S I R research have been concerned with the problem of industrialization and urbanization - with problems associated directly or indirectly with the national environment. The problems have been intensified, furthermore, by the need to take into account the introduction to industry of a hitherto relatively industrially backward people - the Bantu - the mainstay of the Republic's labour force.

Thus,what was needed in South Africa was not simply basic research or applied research but a blend of the two - applying known techniques and knowledge to strange and hitherto untried conditions. As such, the nature of the research was essentially economically orientated, aimed at building up the "economic infrastructure" of the Republic in order to remove bottlenecks or obstacles to future economic growth, insofar as this is possible through scientific and technical means. Much of the present day research conducted in the Republic is of this nature. Space does not, however, permit a description of all the research in the Republic, and a brief description of some of the research conducted by the C S I R instead will be outlined

In general, these problems are threefold: those associated with local products, those pertaining to the physical elements of the environment and those of the human environment. For example, the research programmes in the chemical field (National Chemical Research Laboratory) deal generally with studies into the basic composition of local raw materials (e.g. clay, wood, animal and vegetable fibres) in relation to industrial processing and this is extended to cover studies of the functional performance of materials in use.

A natural consequence of development and industrialization in any country is the problem of water supplies, effluent treatment and disposal, and sanitation. In South Africa these problems are intensified by the relatively small number of permanent streams and the C S I R (mainly through the research activities of the National Institute for Water Research) is charged with determining a scientific basis for planning the most effective use of water supplies. A further problem in South Africa is that there are several localities which possess development potential in economic terms but which lack the water supplies necessary to tap (!!) this potential. The C S I R research programme thus has many facets,ranging from hydrobiological surveys of streams and rivers,to oceanographic research in coastal waters in relation to the disposal of effluent in the sea, as well as geophysical studies to determine the underground volume and flow of water, and to studies aimed at the conservation and reutilization of water by factories.

In the field of atmospherics, the National Physical Research Laboratory is concerned, inter alia, with research into conditions for radio propagation - including ionosphere sounding and predictions, noise-level recording, the performance of radio aids to air navigation in high noise-level conditions, and the use of radar in studies for cloud physics.

With the activities of the National Mechanical Engineering Research Institute, the C S I R is active in research into the ventilation of mines and the development of the design for the huge fans required. Such research is far reaching in its implications when one considers the great depths (excess of 16,000 feet) to which many of our gold mines extend. In this connection, the C S I R has also been called on to assist the Chamber of Mines in the development of a climatic chamber and human calorimeter for use in applied physiological research into health and work performance under conditions of high temperature and humidity in deep mines. South African climatological conditions, with abundant sunshine most of the year round,have also stimulated research leading to the development of successful solar water heaters for domestic purposes.

On the more problemmatic front, a factor to be considered was the drift of people from the rural to urban areas with industrialization in South Africa and the problems this imposed, particularly the problems caused by the tremendous influx of a racially different people, steeped in their own culture and traditions. The immediate problem of course was the shortage of housing which was a formidable factor after the Second World War. The C S I R, with its National Building Research Institute,took the lead in an intensive scientific approach to the problem and considerable success has been shown; for example the expense of satisfactory lowcost urban housing has been reduced to about one half of the cost ruling 14 years ago, and this despite the rising costs of labour and materials. The techniques evolved have since been successfully applied to the designs of schools and hospitals, and,within its laboratories and through the use of in situ tests, the C S I R is investigating the use of industrialized housing techniques in South Africa. These techniques hold much promise for the problems of the building industry, especially in view of recent developments in the field of timber housing with which the C S I R has been extensively concerned.

Urbanization and industrialization have also introduced the menace of air pollution, a problem of serious proportions in the northern, heavily industrialized areas of the country where anti-cyclonic conditions prevail during the winter months. Through the efforts of the National Physical Research Laboratory with its Air Pollution Research Group, the C S I R has paved the way in arousing public interest in this problem through the measurement of pollution. The C S I R also conducts research on methods and equipment for smoke abatement suitable for use at various pollution sources - an example at point is the design for a particular chimney for use in Bantu townships, a major source of pollution. The recording of radio-active fallout is also a responsibility of the C S I R.

Of special economic importance to any developing country is the role of adequate transport facilities in the economic infrastructure. In recognition of the ever increasing distribution problem which economic development brings through geographic specialization, the C S I R, with its National Institute for Road Research, has a comprehensive research programme in the field. An example of the economic implications of some of the research carried out by the Institute is provided by the results of a research project studying the roads system in South Africa, which results show that although rural gravel roads carry only 33 per cent of the mileage travelled on all rural roads, they absorb 80 per cent of the expenditure on the maintenance of the rural road system.

We have mentioned the difficulties engendered by the shift of the Bantu peoples to the towns as a natural consequence of industrialization. One particular problem being dealt with by the National Nutrition Research Institute at C S I R is the radical change in the way of life - and in particular in dietary patterns - which the rurally-orientated Bantu must undergo. Consequently the C S I R has been engaged on an intensive study of the dietary status of all sections of the population to develop satisfactory, and inexpensive, food supplements. At the same time, the efforts of the National Chemical Research Laboratory have been instrumental in providing a scientific basis for the production and distribution of Bantu beer on an industrial and commercial basis. These efforts assume special importance when we realize to what extent the South African economy is dependent on Bantu labour.

Closely akin to the above, are the problems in South Africa of adaptation of management procedures to circumstances in which employees have no traditional background of industrial employment; which problems are intensified by the illiteracy of a large section of the population long accustomed to the conditions of a simple subsistence economy. Research into the development of techniques for the selection, classification, and training of recruits, as well as the study of job evaluation, motivation and incentives has involved the National Institute for Personnel Research of the C S I R in applied industrial psychology.

The needs called forth by urbanization and industrialization in South Africa can thus be regarded as important factors influencing the degree and nature of much research conducted in South Africa, particularly by the C S I R. From one point of view, this research can be regarded as pure or basic research dealing with the development of scientific knowledge about local products, processes, and the human and physical environment in the Republic. More important, the research can be regarded, not as strict basic research according to our definition, but as orientated basic research, in particular growth-orientated basic research, designed to pave the way for future economic progress by eliminating many of the problems and stresses arising from previous development, and its concomitants, industrialization and urbanization. The activities of the C S I R in regard to science and research into defence and national security measures (an activity of considerable size) are closely related to these needs of a progressive country.

The above activities, in conjunction with those mentioned in regard to universities, museums, etc., illustrate the initiative, and great strides taken by the C S I R in its programme to advance "science for science's sake" in the Republic.

Some regard research of the growth-orientated type mentioned above as a form of scientific-technical research in the socio-economic field. Briefly, this view can be regarded as a sequence of activities designed at overall social and economic national prosperity: the object of research in the housing field is, first of all, to reduce the costs of housing and thus rentals;

which in turn makes available more money for food. The aim of nutrition research is to prepare an adequate balanced diet at the national level which is within the means of all sections of the population; in turn, improved nutrition can reasonably be expected to result in greater ability to maintain sustained intellectual and physical effort. Improved management techniques, adapted to the special needs of different population groups, in combination with the other factors, should result in real productivity increases, higher wages and purchasing power and, ultimately, general economic development.

The research programmes of the C S I R are essentially designed to provide a factual basis for policies aimed at developing this sequence of events to promote economic growth at the national level, and consequent improved living conditions for all concerned.

B. Research in the Service of Industry.

Today South Africa can be legitimately regarded as an industrialized country, well advanced in the technological revolution. The changes from an economy based almost exclusively on agricultural and mining activities, a process which began in the nineteen twenties, has accelerated greatly since the Second World War.[1] In this situation, the C S I R which, during the past 20 years, has succeeded in establishing science on a reasonably sound basis in South Africa and,insodoing,has contributed considerably to the development of the economic infrastructure of the Republic, has had to introduce measures to assist industry with problems of technological innovation. For, as we have argued, the present day technological era demands a continuous and increased output, and application of, new and existing technical advances.

In this era, we have seen how South Africa, in common with the stage of economic development attained in most civilized countries, has experienced an increasing demand for the services of scientists in industry, since the engineers and technologists are demanding more and more precise and de-

1. Since 1945, the contribution to the geographical income of private manufacturing alone has increased from 19.9% to 23.1% while, during the same period, the contribution of mining, agriculture and fishing together declined from 26.7% to 25%.

tailed information about materials, products and techniques. Moreover, which information can be obtained with speed and accuracy only by using the latest and most refined scientific techniques. The unfortunate problem is, however, that private firms can seldom commit themselves financially to maintaining a wide range of specialized equipment and qualified scientists. It is in the largest organizations only that services of this kind can be kept fully and efficiently occupied on research connected with the production of a single firm.

The characteristics of a technological production system demanded that South Africa's economic growth be largely dependent on the rate at which existing technology and new technology could be introduced in the new environment. Few firms and industries are characterized by the size and organizational and functional nature for research to fulfil the above requirements. In some cases, such as in the instance of foreign-owned subsidiaries, the difficulty was circumvented in some measure by the importation of know-how and necessary manpower. But for South African industry as a whole, and in particular the small firm, it was a very real problem which had to be met, and still confronts us today.

As we have seen in the terms of reference for the C S I R as set out in the Act, the C S I R was organized in four main ways (a) to cater for research problems of broad national importance, and (b) to help industry. Briefly these are:

. research aimed at the solution of problems arising from the introduction of industries into a new socio-economic and physical environment. Examples were the rapid urbanization of a rural population and the attendant problems of housing, nutrition, road construction, water supply and air pollution;

. research which, although not of immediate vital importance to a particular company, is of general importance to a number of companies and which is sometimes jointly supported by groups of firms and public bodies, for example, long-term projects on sewer-corrosion, foundry sands, air pollution and timber usage;

. research fellowships have been introduced to assist companies wanting advice in some field before committing themselves and for companies desiring long-term fundamental research for which they themselves are unequipped;

. research into problems of an ad hoc nature carried out by the C S IR on behalf of industries on a contract basis.

The services provided to South African Industry by the C S I R can be described then under three general headings:

1. Through its network of national institutes and laboratories, the C S I R handles the problems of industry in general, and deals with the communities and environments in which industries operate. This activity has already been discussed under the section of research in the public sector above. From the summary above, we have seen how, in an emerging industrial economy, there is an urgent and obvious need for government to initiate, and assist in, the creation of conditions in support of industrial development in order to reduce or eliminate obstacles and bottlenecks to growth and to prevent undesirable social conditions attendant on industrial development and urbanization. As such, the C S I R does not provide a direct service to specific industries, but is concerned with putting the economic and industrial infrastructure as a whole on a sound progressive footing and thereby assisting South African industry in general to expand.

2. More directly, the C S I R endeavours to assist industry by undertaking research of interest to a number of firms or even to whole sectors of industry. In the first instance, the C S I R has introduced an industrial research association scheme, similar to that of the D S I R in Britain, and the principle here is, that if adequate financial support from industry is guaranteed, an autonomous industrial research institute may be established with the C S I R contributing towards its finances. The government has actively participated in this development of research for specific sectors of manufacturing industry in South Africa through an arrangement whereby part of the C S I R's annual parliamentary grant is made available for this purpose. At present, the leather, fishing, paint, and sugar industries are served by the above type of research institute, with the South African Wool and Textile Research Institute being an integral part of the C S I R and serving the textile industry in South Africa. Some measure of the present and potential economic importance of the abovementioned institutes can be gauged from the following:- [1)]

1. Data obtained from C S I R Annual Report, Pretoria, 1965.

- The gross value of output of the industries served by the Leather Industries Research Institute (L I R I) amounts to approximately R121 million and the total value of exports to R32 million. L I R I is supported financially by virtually all the leather and allied products sector in South Africa, and has numerous outstanding technical achievements to its credit.
- The fishing industry is of strategic importance in the South African economy, both by merit of its sheer size and by the quality of its products. It employs roughly 16,000 persons of all races and the approximate nett f.o.b/f.o.r. values of the main fishing products sold in the local and export markets during 1964 were R8.6 million and R45.5 million respectively. Bearing in mind that South Africa is the accepted world leader in such subjects as the fundamental aspects of fish flour production, spontaneous combustion of fish meal, and odour abatement of fish reduction plant, and the fact that the Fishing Industry Research Institute enjoys practically a hundred percent membership from the South African fishing industry, F I R I appears to have a strategic role in the development of the fishing sector of the economy.
- Sugar is one of South Africa's most dynamic export industries; South Africa is regarded as the world's fourth largest exporter, and the sugar industry in South Africa earns approximately R100 million per annum and pays out roughly R25 million in wages. The Sugar Milling Industrial Research Institute (S M I R I) has been instrumental, inter alia, in assisting the industry to meet the specifications of other countries, and thus in securing export contracts.

Furthermore, the C S I R has set up a limited number of industrial research units and groups within its national research institutes, for example the Bantu Beer Unit, Timber Unit and Ceramics Unit. These units are concerned with the technologies of specific industrial sectors and form the nucleus from which a research institute may later grow.

The basic function of research under this head can be regarded as technologically orientated, or research undertaken with the intention of application in a particular sector of the economy and, as such, often forms the basis for technical innovation. Much of the fundamental or basic research also is orientated towards eventual importance to a particular industrial sector. Other research laboratories or institutes such as chemistry, physics, mechanical engineering and mathematics are more 'discipline orientated', i.e. they are organized more on the basis of the main disciplines in science and engineering than of technologies, and only serve particular industries with research of an applied or development nature through their various specialist divisions and departments.

3. In much the same way as do the famous American industrial research institutes, such as the Mellon Institute and the Massachusetts Institute for Technology, the C S I R also provides direct research services to industry. In the first instance, a firm wishing to explore some new field can establish an industrial research fellowship within one of the C S I R research laboratories or institutes. Personnel appointed under this system investigate the fields designated by the sponsoring firm for a predetermined period. If the results appear promising and the field begins to show possibilities for development, the research staff working on the project are often transferred to the firm's laboratory to continue the development work.

Secondly, and more commonly, research is undertaken on behalf of industrial firms in order to solve specific problems encountered by them. Such research is invariably of an applied or development nature, and each investigation is covered by a specific contract, in terms of which the sponsor pays the full cost of the investigation in return for exclusive rights to the use of the results of the research.

In general then, one of the main purposes for which the national research laboratories were established was to make available to industry the modern research facilities which only a few of the largest undertakings can provide for themselves. Many of the industrial processes and products in South Africa can be improved by research, and research is frequently necessary before overseas practices can be introduced into South Africa and adopted to meet local conditions and to use local raw materials. Through the activities outlined above, the C S I R has done much to meet these conditions.

The important role played by the C S I R in the training of what I shall call "technologically aware" personnel must also be remembered when discussing C S I R services to South African industry. I have already stressed the all important need in industry for people trained in, and constantly aware of the economic benefit of, the latest scientific techniques and, in particular, their application to industry. The C S I R provides an excellent scientifically equipped and modern training ground for such personnel, and this, coupled with its extensive overseas training programme already pointed out, has been instrumental in providing South African industry with sorely needed human material, and more important in equipping young people to meet industry's needs.

In conclusion, it is difficult, in research economics, to remain for long off the subject of research application, and the C S I R recognizes the importance of this field.

6.6.3 THE APPLICATION OF RESEARCH

A. Invendicor

The bulk of the C S I R research efforts in both the pure and applied research fields can be said to be of an exploratory nature designed to open up new fields of scientific knowledge and the results of such investigations are communicated by way of publication or addresses to various societies or simply by personal contact. The effect on economic growth of such research can be of a long term nature only. Research leading to invention and innovation is a more short term factor in the growth process. However, such research will not have its full effect on the productive process unless the results obtained can be applied to industry quickly and effectively.

In Britain, the rather widespread opinion that Britain was falling down on the industrial application of research, was one of the factors responsible for the establishment of the National Research Development Council. The N D R C provides capital for developments involving technical innovation and was designed to fill the gap caused by the reluctance of private interests to put up capital for enterprises which of their very nature carried a considerably higher risk than normal. The N R D C has its own capital and can exercise greater flexibility in the conditions of partnership it negotiates for different ventures. Sometimes it gives a direct loan to a single firm to develope an idea of its own, while at other times it introduces a project to several firms and allows each to develop away from the original blueprint in its own direction. [1)]

1. The Hovercraft is an example of such a development.

As such, the N.R D C has pioneered many successful projects.

Along much the same lines the Inventions Development Corporation (Invendicor) at the C S I R has the main objective of putting research into practice. The research handled by Invendicor is, however, of a rather special nature, referring specifically to a "piece of hardware," [1] such as a scientific instrument, a new material or possibly a chemical process, or inventions in the broad sense of the word.

In the past, the C S I R was content just to publish the research results, but, as was the experience overseas, industry was not always quick to take the matter up from there. This is understandable when we consider that the research itself is only a part (often a minor part) of the innovative process; as mentioned, a further usually far more expensive activity - development - is called for involving the construction of pilot plant, prototypes, testing, etc. In addition to the technical activities required, commercial efforts are also often called for, for example market and consumer surveys, before commercial production can be undertaken and a profit made. This profit is by no means assured, as innovation is by nature uncertain and usually involves an abnormal amount of risk. Consequently, before the entrepreneur can be expected to accept the risks involved in exploiting a new invention, it is necessary to ensure reasonable protection from competition, so as to make the risk worthwhile.

Accordingly, the policy of Invendicor is to patent new inventions and to seek an industrial associate to participate in the development programme with the option of securing a manufacturing licence should the project ultimately prove to be commercially attractive. As stated, the cost of development activities is frequently extremely high, and it is a further policy of Invendicor, where possible, to seek industrial support at the earliest possible stage in the research investigation since often only industry is in a position to meet these costs. This has not proved an easy task, since South African firms, as can be expected in a relatively young developing country, are often reluctant to take up the results of indigenous research, generally regarding

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1. Mr. A.M. Schady, Head, Invendicor, C S I R names it.

it better business sense to invest in tried "know-how" from abroad, and arranging for its local manufacture. Certainly the risks are less than embarking on the promotion of a completely new invention.

Nonetheless, Invendicor has had considerable success in achieving its objectives, so much so, that in the main "industry earns a conservative ½ million every year from C S I R Inventions."[1] The C S I R aims mainly at the exploitation of its inventions by indigenous firms, as is the case for example, of the "Tellurometer." However, this is not always the case and occasionally special circumstances arise to prevent this and a licence to manufacture is granted to an overseas firm.[2]

Case studies at present being undertaken by the author will seek to show that the results of the above promotional activities have been far from negligible, particularly in the sphere of the development of overseas markets and the earning of foreign exchange. Perhaps of equal importance in the long run is that this close co-operation with industry, particularly in regard to the "pay-off" from successful research, will engender a heightened interest in the value of indigenous research.

B. Information

This is perhaps one of the most critical factors impinging on the value of research, namely the question of information. In accordance with its Act of establishment, a considerable part of the C S I R's activities are directed towards furthering research on behalf of industry. However, the problem is that in many instances, industry is not fully aware of the facilities available to it. In other words, there are many instances where the material for innovation exists (in the form of completed, and successful research investigations) but is not made use of. Many firms too are not aware that the C S I R and other research bodies can assist them in solving their technical problems both of a short and of a long term nature. The prime need here is thus for information, on what has been, is being, or can be done, in research of an industrial nature.

1. Schady A.M.; Cashing in on Research, Industrial Review of Africa, June 1960.
2. For example, the Wadley Receiver licensed to a British radio firm.

To meet this need the C S I R, through its information and Research Services, regularly arranges short industrial symposia or full-scale conferences to bring industry and science together. For example, a symposium with the theme "science in the service of industry" was recently held in Durban in collaboration with the National Development and Management Foundation of S.A. for the purpose of promoting communication between the C S I R and Natal industrialists. Other recent symposia and conferences dealt with mould infestation of foodstuffs, human factors in industry, and corrosion.

The laboratories and institutes, of course, through regular publication of results also play an important role in the diffusion of information. However, the need for information is not limited only to scientific and technical information. Experience in the laboratories obtained from handling inquiries for technical advice and assistance indicated that, more often than not, the enquirer's problems were both organizational and economic as well as technical. It became apparent that a prerequisite to the effective solution of the immediate technical problem, and the use of the solution, was a systematic study of the industrial operation as a whole. It was frequently found then, that, in certain circumstances, operational research or economic analyses might provide the most effective initial approach to research on industrial problems. Hence the establishment of the Economic Technical group in the C S I R.

Of particular importance in the sphere of research application is the need for technical advisory services for:

> "....Some industries may shut their eyes to the need for research, but sometimes whole laboratories shut their eyes to the needs of industry or to make results intelligible. The purpose of a given piece of research and the way it could be used in industry very often needs to be spelled out in fairly simple language before the average production manager can begin to grasp its importance. This may reflect badly on a company's lack of properly qualified staff but scientists must take industry as they find it." [1]

Studies undertaken at the C S I R [2] have indicated that published information aimed at overcoming the above problem plays a relatively minor role except

1. <u>The Economist</u>, London. July 22, 1961.
2. e.g. Grant, Joan: <u>Information for Industry - A Study in Communication</u>, C S I R Research Report 299, Pretoria. 1964.

in industries possessing their own research laboratories. This is particularly the case when one considers the numerous small- and medium-sized firms, operating essentially on a short-term profit basis, who are frequently unaware of the specialized information centres and research institutes available to them, and even if so aware, lack the specialized, or "research-minded" personnel to interprate, evaluate, and relate the information to their own needs. The problem is intensified by the enormous expansion in output of scientific literature common to all countries of the world which puts a superhuman burden on the individual, in his own specialist field, to deal with.

These problems are receiving attention from the C S I R within its Department of Information and Research Services.

6.7 SUMMARY AND GENERAL CONCLUSIONS

An apology would seem due for the somewhat extensive description of the activities of the C S I R in this chapter on research in South Africa. One would have liked to include the general research effort of the entire country but unfortunately it was not possible to obtain adequate information on industrial research carried out by the business enterprise sector of the economy. Furthermore, it was felt that to cover the research activities of other South African research organizations (such as those within the general government sector) in addition to the C S I R would have proved a time-consuming task and one, moreover, not strictly within the scope of this study.

A description of the C S I R provided the focal point of this chapter for two main reasons: Firstly, the date of establishment of the C S I R is generally regarded, both as the turning point in the history of science in the Republic, and as the turning point in the industrial development of the S.A. economy. Secondly, a description of the structure of the C S I R and the nature of its activities in the sphere of basic and applied research aptly describes the close relationship between the above two historical developments, and illustrates the danger of viewing the development of science in isolation to the progress of industry. The central theme of this dissertation has been largely taken up with the application of research to economic, chiefly industrial, pursuits, and, in the author's opinion, the C S I R provides an outstanding example of a research organization actively aware of the importance of the above application.

In conclusion, an outline of the development of science and scientific research in the Republic reveals that this development can be traced through three distinct time periods. These are:

1. <u>Before Union in 1910</u>

During this period - the "pre-science" period in South Africa - there was little awareness of the importance of science and research to national, and more particularly, economic prosperity, and still less facilities and personnel for research. The only research activity consisted of sporadic research by gifted individuals at the universities and museums and by visiting scientists. In large measure this was the result of the prevailing economic and social structure, particularly the absence of large-scale industrialization, and, all in all, the expenditure on research in South Africa could be regarded as negligible.

2. <u>Union to End of World War II - 1945</u>

While many of the Western nations were rapidly developing organized research facilities, conditions in South Africa had not yet reached the stage to warrant this activity. True, there were considerable strides made, particularly in the government sphere, where the importance of research always seems to strike home first. There was an expansion of government research, particularly in agriculture and veterinary medicine, mining and geology, and public health, but it is extremely difficult to isolate research activities from the other functions of the performing organizations.

At the same time, it was realized that the wholly government controlled research organization was not the only, and most efficient, research organization. During this period, two independent co-operative industrial research institutes - the Sugar Experiment Station and the Chamber of Mines Research Laboratories - were established, as also two co-operative industrial research institutes with state support - the Fuel Research Institute and the South African Institute for Medical Research. Although, in all these cases routine services and non-research activities appeared to predominate, [1] and although the universities offered no facilities for research, it could be seen that economic growth and industrialization were gradually emphasizing the need for more extensive and better organized research services.

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1. It is difficult to be specific about research activities since no reliable survey of measurement was available.

3. Since World War II - 1945 plus

Two broad sets of factors were responsible for the rapid growth of science in the Republic in this period. In the first instance, the numerous technical problems confronting South Africa engaged in a global war called for a different industrial approach, and, in particular,a new alignment between government and industry. It was no longer sufficient merely to protect industries against foreign competition through the application of the customs tariff, or to come to their aid by way of subsidies or other financial means. A much wider and more fundamental approach on a technical level, whereby research carried out on a national scale in the interests of the economy as a whole would be made available to industry and other sectors of the economy, had become necessary. This was one of the reasons which led in South Africa to the establishment of the C S I R in 1945 and scientific activity in South Africa has expanded at an extremely rapid rate over the past two decades. In the second instance, this expansion has been based on a remarkable expansion of industrial activities, and upon an increasing appreciation of the role of science in the exploitation of natural resources.

In fact, one of the C S I R's main objectives has been to collaborate with secondary industry in such a manner as to ensure in general the optimum use of all scarce resources, and, in particular, through applied industrial research to arrive at:

1. an improvement of existing products, processes, and manufacturing methods,
2. the development of new products and processes,
3. extended uses for existing products and materials (including waste materials),
4. the modification of existing processes to suit local conditions and to enable the use of local raw materials,
5. the development of means for ensuring the effective utilization of natural resources.

Thus in conjunction with its basic research programmes and research of general benefit to industry, C S I R has been extremely innovation conscious and has organized itself to that end. At the same time, it has done much to put university research on a sounder footing. During this period, the universities have emerged as important centres of research, particularly basic research, and have provided the homes for many research units. At the same time we have witnessed a remarkable extension of research in the activities of the government departments, as well as the establishment of government sponsored research institutes, e.g. the Wattle Research Institute and independent research institutes, e.g. the Diamond Research Institute, both common features of the overseas research scene. In the field of industry, the reliance on parent companies and the importation of foreign technological know-how has been a steadily decreasing factor in this period and today numerous large firms have set up separate research departments. At the same time, increased attention is being paid in South Africa to the problems of communication between science and industry, particularly on the technical information level.

In conclusion, South African research activities have come a long way since the turn of the century. But the path ahead must not be assumed to lie smooth and trouble free. Scientific research in South Africa has expanded remarkably, but the growth of an appreciation for scientists and technologists has lagged somewhat behind, and, in the face of competing opportunities, recruitment to the scientific profession has not been occurring on an adequate scale. We have witnessed a growing shortage of scientists and engineers, particularly research-trained scientists and engineers, which has only recently started receiving the attention it so richly deserves. The crux of any organized research programme lies, to the economist at least, in the application of those research findings in the social and economic structure. Hence the problem of adequate manpower. If measures to tackle this problem prove to be as effective as those leading to the provision of science facilities over the past twenty years, science should be able to play its full part in the development of South Africa.

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