ECONOMIC ASPECTS OF SCIENTIFIC RESEARCH IN SOUTH AFRICA

by

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PREFACE

This dissertation is dedicated to the South African Council for Scientific and Industrial Research (CSIR) in recognition of its attempts to establish in South Africa an adequate scientific infrastructure. For not only has the CSIR championed the cause of science, but it has shown as well an acute awareness of the need for suitable scientific co-cultures. The economics of science, the task of science within industry, the information problem and documentation explosion; are all examples of topics with which the CSIR is vitally concerned. As may be expected, the present study was conceived and planned within the sphere of influence of the CSIR. It was completed while the author was employed in the Industrial Economics Division of the Council.

The study itself was undertaken under the guidance of Professor J.L. Sadie of the Department of Economics of the University of Stellenbosch. His unrestrictive and encouraging leadership made the preparation of this dissertation a rewarding and enjoyable experience.

Others to whom the author is indebted include:

Mr. L.A. Beard, a former Head of the Industrial Economics Division of the CSIR and at present Managing Director of H. Alers Hankey Limited; for defining the subject matter and for pointing out its potential as a field of study;

Professor A.E. Scheurkogel of the University of Stellenbosch, (and also a former Head of the Industrial Economics Division); for firmly entrenching research economics as a recognized field of enquiry in South Africa.

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PART I

INTRODUCTORY REMARKS AND BACKGROUND THEORY

1. INTRODUCTION

1.1 The need for a general theory of science[1]

It was Francis Bacon[2] who, in the first three decades of the seventeenth century, gave us the first social over-view of endeavours in the field of natural science and who stressed the need for understanding the circumstances of scientific research. Since then the need for a general (social) theory of science has been urged upon mankind from a number of quarters.

One plea, which is of particular relevance in that it indicates the scope of such a theory, came from María Ossowska and Stanislaw Ossowski who, in 1936, argued in favour of a unified field of knowledge dealing with the sociology, psychology, economics, history and philosophy of science, as well as with the organization of the overall scientific effort.[3]

This unified field of knowledge was provisionally termed the "science of science". Other names which have been suggested include "metascience"[4] and "scieonomics"[5], but none of these have achieved general recognition as yet.

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1) Throughout this dissertation the term "science" will be used to indicate the natural sciences only. Whenever the social sciences are referred to this will be explicitely stated.

2) The advancement of learning, published in 1605, Novum Organum, published in 1620, and New Atlantis, published in 1627.

3) OSSOWSKA, María, and OSSOWSKI, Stanislaw: "The science of science", Minerva, vol. III, no. 1, Autumn 1964, pp. 72 - 82.
This is a reprint from: Organon vol. I, no. 1 (Warsaw), 1936, pp. 1 - 12.

4) Mentioned by; DEDIJER, Stevan: "Measuring the growth of science", Science, vol. 138, no. 3542, 16 November 1962, p. 787, and taken from MORRIS, C., in International Encyclopedia of Unified Science, vol. 1, part 1, Chicago, 1955 (University of Chicago Press).

5) FALK, John, and O'DEA, Marjorie: "Science technology and society: an outline of the development of scieonomics", Australian Quarterly, vol. 39, no. 4, December 1967, pp. 50 - 65.

With the rapid development of science in the past decade or so, coupled with the virtually universal phenomenon of government involvement in science, there has been a growing recognition of the potential value of the "science of science" as a rational basis for scientific policy-making and planning. The task of the science of science, according to Dedijer, is .... "to help decision makers improve .... (1) the productivity of research activity, and (2) the productive application of research through more informed and more rational decision."[1)]

But in spite of the growing interest in the science of science, and in spite of its utilitarian value, the entire field of knowledge is still largely underdeveloped. The present dissertation is an exploration into this field.

It is the objective of this study to contribute towards a greater general understanding of science by examining one aspect thereof in greater detail, namely the economic aspect. The whole approach will be in the economics tradition and an attempt will be made to review science as a purely economi phenomenon. Particular attention will be given to South Africa.

It is realised of course, that this is somewhat of a fragmentary approach. It is justified on the grounds that the "science of science" covers such a variety of topics, ranging from the internal process of progress in science, to the effects which this has on the social and economic environment, that no single discipline can be called upon to deal with it effectively. It is at this stage necessary to call upon various disciplines to render different aspects comprehensible.

Nevertheless it is fully realised that the economic aspects of science are but part of a much broader picture, and attempts will be made throughout

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1) DEDIJER, Stevan: "The science of science: a programme and a plea", Minerva, vol. IV no. 4 Summer 1966, p. 499.

to take account of the wider association as far as possible without deviating too much from the strictly economic character of the study.

1.2 Contents of the dissertation

This dissertation is divided into four parts.

The first part introduces the subject matter and deals with the present state of knowledge concerning the economic nature of science. Studies of the importance of technological advance in economic growth are reviewed and the various factors contributing to technological advance examined more closely. Thereupon a special Section is devoted to a review of available empirical evidence on the direct economic impact of science.

In the second part the focus is shifted from the overall research and development scene to conditions in South Africa. The South African scientific structure is briefly reviewed and the present expenditure on research and development discussed in detail. Thereupon the aggregate economic impact of research in South Africa is investigated. This cannot be directly calculated and can only be indirectly deduced. The research needs associated with the various stages of economic development are outlined and the particular stage is identified in which South Africa finds herself. Specific recommendations are made to bring about a research structure which would more adequately meet the requirements of the South African economy.

In part three the methodology of formulating scientific policy and of planning science in terms of economic objectives is investigated. First of all an attempt is made to develop a decision-making model for scientific policy into which economic considerations may be integrated. A next Section deals with a lower level of planning and is concerned with methods for merging scientific and economic planning techniques. The final Section recounts South African experience of the economic approach to scientific policy and planning.

In the fourth part of the dissertation the conclusions drawn in the main body of the study are restated and these are then followed by certain recommendations for further study and for Government action in matters of science.

2. STATE OF KNOWLEDGE OF THE ECONOMIC NATURE OF SCIENCE

2.1 The rôle of science in the economy - some historical perspectives

A. Origins and growth of science

We will begin by reflecting on the origins of modern science, i.e. science as we know it in the modern Western context, and then proceed to discuss the development of economic doctrines in relation to the growth of science.

What do we mean by modern Western science? According to Einstein: "Development of Western science is based on two great achievements, the invention of the formal logical system (in Euclidean geometry) by the Greek philosophers, and the discovery of the possibility to find out casual relationships by systematic experiment (Renaissance.)"[1)] Today these two components of scientific method are taken for granted and there is very little which can lead us to suppose that they were not always used in association with one another. However, there are those who hold that prior to a certain stage in the history of mankind, namely mainly during the sixteenth century, the fusion between these two elements had not yet occurred and modern science as we know it could not have existed.

Their case is based on the argument that the two components of the scientific method were in practice separated by a social barrier - logical training being reserved for upper class scholars, while: "experimentation, causal interest, and quantitative method was left to more or less plebeian artisans".[2)]

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1) Quoted in: de SOLLA PRICE, Derek J.: Science since Babylon, New Haven, 1961 (Yale University Press) p. 15.

2) ZILSEL, Edgar: "The sociological roots of science", American Journal of Sociology, vol. XLVII, no. 4, January 1942, p. 544.

It is argued that the manual labour associated with experimentation was unacceptable to the upper class citizens - a point better appreciated when it is borne in mind that laboratories had not yet come into being and "experimentation" must therefore have been a very crude affair. Evidence is adduced that the learned disputations of the scholars, (always written in Greek and Latin) and the practical observations and trade "recipes" of the skilled artisans (always written in the vernacular) existed side by side without cross fertilization. According to Zilsel, the father of this theory: "Science was born when, with the progress of technology, the experimental method eventually overcame the social prejudice against manual labour and was adopted by rationally trained scholars".[1)]

This fusion took place towards the end of the sixteenth century and is epitomized by the work of Galileo. Zilsel's observations on Galileo are particularly pertinent and we may be permitted an extensive reference: "The shape of the curve of projection had often been discussed by the gunners of the period. Tartaglia had not been able to answer the question correctly. Galileo, after having dealt with the problem for forty years found the solution by combining craftsmen like experimentation and measurement with learned mathematical analysis. The different social origin of the two components of his method - which became the method of modern science - is obvious in the Discorsi, since he gives the mathematical deductions in Latin and discusses the experiments in Italian".[2)]

The Discorsi was published in 1636.

As with all theories dealing with social phenomena, the Zilsel hypothesis on the origins of modern science cannot be accepted without reservation,

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1) Ibid., p. 544.

2) Ibid., p. 556 (my underlining).

and very many qualifications have been proffered. So, for instance, Barber, in his discussion on the achievements of early Greek science, claims that there were also significant advances in "empirical science" in the time of Aristotle.[1)]

It is not the place here to deal with the various deficiencies of the Zilsel hypothesis, as this would lead us to a full-scale investigation on the theories concerning the origins of modern science. Nor is it crucial to the line of argument which will be pursued. It is probably sufficient to state that modern science as we know it, came into existence during the sixteenth and towards the beginning of the seventeenth century. Since then it has grown rapidly and in the course of this growth has changed its social character considerably.

The seventeenth century saw science in Europe being cultivated as a hobby of gentlemen. This period also saw the establishment of various scientific academies throughout Europe and Britain. The Academia dei Lincei was established in Rome in 1601[2)] with substantial support from the Barbarini family. This was followed by the establishment in 1657 of the Academia del Cimento with backing by the de Medicis. In England, the Royal Society was established in 1660, while the Académie des Sciences of France was established soon afterwards in 1666.

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1) BARBER, Bernard: Science and the social order, New York, 1962 (Collier Books) pp. 69 - 70.

2) According to BERNAL the first academy of modern times was founded by Cosimo de Medici in Florence in 1438. He points out that ...... "it was a platonic academy, but one definitely breaking away from scholastic limitations and the prototype of the scientific academies that were to follow".

BERNAL, J.D.: The social function of science, London, 1939 (George Routledge and Son Ltd.) p. 19. Bernal describes the Academia dei Lincei as the "first scientific academy" (p. 21).

In Britain the eighteenth century saw a marked change in the social status of the practitioners of science. It may be said that the nature of science in Britain changed from a hobby of gentlemen to a pursuit of tradesmen. According to Mendelsohn; "Sixty seven percent of the English scientists of the early seventeenth century were graduates of either Oxford or Cambridge. By the end of the eighteenth century, this figure had dropped to a mere 20 per cent."[1] This trend may be explained by the shift of scientific activity from London to the industrial centres of the British Midlands. The latter part of the eighteenth century also saw the establishment of societies in these industrial centres which had as their object to bring together: "manufacturers, scientists, and men of letters".[2]

While the link between science and industrial technology was thus forged, academic recognition of science as a field of learning had yet to come. Science in Britain arose outside the established universities of Oxford and Cambridge, and whenever it was taught, it was done in institutions far removed socially from the accepted seats of learning and aptly designated "dissenting academies".

Meanwhile in Europe, France was being ravaged by the revolution of 1789, and while this had an ill effect on all scientific institutions associated with the <u>ancien regime</u>, the revolution gave birth to a new concept of education associated with scientific research. The establishment of the Ecóle Polytechnique in 1794, gave the world "a model upon which other nations fashioned their new systems of scientific and technical training".[3

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1) MENDELSOHN, Everett: "The emergence of science as a profession in nineteenth-century Europe", in; HILL, Karl: <u>The management of scientists</u>, Boston, 1964 (Beacon Press) p. 5.

2) Ibid., p. 6.

3) Ibid., p. 9

4) From an educational point of view it is interesting to note that France at that stage led the world in the training of engineers - The Ecole Nationale des Ponts et Chaussees, established in 1747 by the French engineer Perrone was the first institution to offer academic training to engineers. See: NAUDE, S. Meiring: Die rol van die wetenskap in ingenieurswese, <u>Tegnikon</u>, vol. 14, no. 4, Des. 1965, p. 139.

The students attending the Ecóle, received training in both theory and experimentation, which may be considered one of the greatest educational innovations of the day. This example spread rapidly and, in particular, became embodied in the new German universities and technical institutes which emerged as a result of a process of decentralization of education in nineteenth-century Germany.

According to Bernal the economic effects of their development were far reaching: "In Germany, however, industrialization was far more intense; science was being used on quite another scale. The Technische Hochschulen were turning out thousands of trained chemists and physicists, who were being absorbed into the laboratories of industry, and in a few years the chemistry of dye-stuffs and explosives for which the foundations had been laid largely in France and Britain, had been captured as part of the new German industry which held the virtual monopoly of the world market."[1)2)]

By the middle of the nineteenth century, the relatively more rapid development of science in Europe gave rise to much concern in Britain and led to particular attempts among the scientific community to ensure the recognition of science by commercial, academic and government interests.[3)] The British Association for the Advancement of Science was established at this stage and apparently achieved much in the resurrection of British science. For the economist, it is interesting to note that: "throughout

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1) BERNAL: op. cit. p. 29.

2) For a most illuminating discussion of the various scientific discoveries which influenced the dye-stuffs and chemical industries see DERRY, T.K. and WILLIAMS, Trevor I.: A short history of technology, Oxford, 1960 (Clarendon Press) pp. 531 - 546. Refer also to HOHENBERG, Paul M.: Chemicals in Western Europe 1850 - 1914, Amsterdam, 1967 (North-Holland Publishing Co.)

3) See in this connection BABBAGE, Charles: The exposition of 1851, or views of the industry, the science and the government of England. London, 1968 (Frank Cass and Co. Ltd.) (First published in 1851 by John Murray of London).

the polemics and pamphleteering of the 1850's and 1860's one finds scientific education urged upon schools and universities not because science was now in the main stream of European thought, but because it would improve the efficiency of manufactures."[1]

The last three decades of the nineteenth century saw the acceptance by the traditional British universities of experimental science as an ingredient in education, and saw the establishment of the Clarendon Laboratory at Oxford and the Cavendish Laboratory at Cambridge.[2]

Probably the most outstanding feature of science in the nineteenth century is its emergence as a distinctive profession[3] with a unique value system and set of rules of conduct. Opportunities for employment became more abundant with the establishment of government laboratories, and laboratories for industrial research associated with business enterprises. The development of science-based industries, such as the chemical industries and electrical manufactures, gave stimulus to scientific education which could be of technical value, and attracted attention for the first time to the possibilities which science held out for large scale innovation.

The history of science in the twentieth century is a history of exponential growth. As a source of industrial competition, as a source of military superiority, and lately, as a source of national prestige, science is being called on increasingly to serve nations. The latest phenomenon in the scientific evolution is possibly the mass mobilization of science to meet national objectives. This was witnessed in the U.S.A. in the 1940's on the Manhatten project, and in Russia and the United States in the 1960's in the so called race for the moon.

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1) ASHBY, Eric: Technology and the academics, New York, 1963 (St. Martin's Press Inc.) p. 31.

2) Ibid., p. 38.

3) MENDELSOHN, Everett: op. cit. pp 14 - 25.

During the past three centuries therefore science has grown into one of the dominant forces shaping the course of history. Today, more than ever before, science finds itself regarded as a determinant of our social and economic structure.

B. Recognition of science in economic writings

It has been pointed out that even in the earliest writings of economists, there is recognition of the economic impact of science. Thus Adam Smith sees the contribution of scientists (or philosophers as they were then called), as part of the phenomenon of the division of labour. Thus Adam Smith asserts: "Many improvements have been made by the ingenuity of the makers of the machines, when to make them became the business of a peculiar trade; and some by that of those who are called philosophers, or men of speculation, whose trade it is not to do any thing, but to observe every thing, and who, upon that account, are often capable of combining together the powers of the most distant and dissimilar objects. In the progress of society, philosophy or speculation becomes, like every other employment, the principal or sole trade and occupation of a particular class of citizens ..."[1)]

In general however, classical economists gave only fleeting recognition to the economic impact of science. Whatever contribution was recognized was regarded as marginal and peripheral to the basic development of the economy. Also the forces governing the supply of science-based inventions were regarded as exogenous to the main stream of economic life and belonging to the same category as sun spots, droughts and international hostilities.[2]

1) SMITH, A: Wealth of nations, Book 1, Chapter 1. As referred to in CARTER, C.F. and WILLIAMS, B.R.: Investment in innovation, London, 1958 (Oxford University Press) p. 149.

2) This also goes for the whole of "technological advance" which the classical economists saw as a spectrum of already completed inventions waiting for new investment to realise their economic potential. For a discussion of this view the reader is referred to: HIGGINS, B.: Economic development, London, 1959, (Constable and Company Ltd.) pp. 87 - 92.

Even among the neo-classical authors there is very little concern with science, even though a certain awareness exhibits itself from time to time. In Marshall, for example, there are fleeting references which lead one to believe that he had at least some appreciation of the economic impact of science. In discussing the productive ability of land for instance, Marshall refers as follows to fertilizer as a product of modern chemical science: "For he can then turn a barren into a very fertile soil by adding a small quantity of just those things that are needed; using in most cases, either lime in some of its many forms, or those artificial manures which modern chemical science has provided in great variety: and he is now calling in the aid of bacteria to help him in his work."[1]

We should not be overly surprised however, that economic theory in the eighteenth century was not particularly laudatory about the rôle of science. The impact that there was had not yet emerged as a beneficial pattern and those consequences which were apparent, frequently showed their effects on the economy in the form of social ills with which the economists were more concerned per se. A similar observation could apply to the nineteenth century as well. Here the lack of interest in the economic impact of science may be explained by the preoccupation of economics with the way in which the social product was allocated among the various proprietors of the factors of production. The growth of that product was of secondary interest.

What is surprising however, is the fact that twentieth century economists, with very few exceptions, gave so little systematic attention to the conditions which lead to industrial innovation.[2] Two reasons are advanced

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1) MARSHALL, A.: Principles of economics, London, 1947 (MacMillan and Co.) p. 146.

2) It is interesting to note that even in recent studies of the histories of individual business enterprises only passing reference is made to the rôle of research and development. See for instance WELLS, F.A.: Hollins and Viyella, a study of business history, New York, 1968 (Augustus M. Kelly) pp. 137, 144, 202.

for this lack of interest. First, there is the complexity of the process of innovation and the fact that it does not yield readily to the usual analytical techniques of economics. Second, the preoccupation of economists during the first half of the century has been very much more with the maintenance of stability and full employment in the economic system rather than with the progress of the overall whole.[1)]

Again this does not mean that the promise of science-based inventions as a stimulus to commercial and social innovations was not recognized. Veblen, for instance is credited with foreseeing: ...."the emergence of a technical elite to harness the divergent interests of business and science"[2)]. Not only do his essays reflect a particularly acute awareness of the impact of science on the economy[3)], but also of the unique growth rate of science which distinguishes it from other social phenomena. Veblen maintains in this connection: "The number and interplay of technological factors engaged in any major operation in industry are related to the corresponding facts of the middle nineteenth century somewhat as the mathematical cube is related to the square and the increase and multiplication of these technological factors is going forward incontinently, at a constantly accelerated rate."[4)]

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1) JEWKES, John, SAWERS, David, and STILLERMAN, Richard: The sources of invention, London, 1961 (Macmillan and Co. Ltd.) p. 3.

2) GOULD, Jay M.: The technical elite, London, 1966 (Frank Cass and Co.) p. 32.

3) See VEBLEN, Thorstein: The place of science in modern civilization, New York, 1919 (B.W. Huebsch) (in particular the title essay - originally published in 1904) and: Absentee ownership and business enterprise in recent times: The case of America, New York, 1923, (B.W. Huebsch) Chapter X, "The technology of chemistry and physics". Quoted in GOULD op. cit. p. 33.

4) Absentee ownership and business enterprise in recent times, op. cit. p. 271, quoted in GOULD op. cit. p.40.

Further recognition of science came from Keynes who wrote a vivid account in 1930 (in the midst of the world's worst depression, when the perspectives of economists could not but have been tainted with pessimism) of the economic epoch upon which the world had embarked and which held the promise of economic abundance derived from science-based technology. According to Keynes: "From the earliest times of which we have record - back, say, to two thousand years before Christ - down to the beginning of the eighteenth century, there was no very great change in the standard of life of the average man living in the civilized centres of the earth. Ups and downs certainly. Visitations of plague, famine, and war. Golden intervals. But no progressive, violent change. Some periods perhaps 50 per cent better than others - at the utmost, 100 per cent better - in the four thousand years which ended (say) in A.D. 1700."[1]

And further: "From the sixteenth century, with accumulative crescendo after the eighteenth, the great age of science and technical inventions began, which since the beginning of the nineteenth century has been in full flood - coal, steam, electricity, petrol, steel, rubber, cotton, the chemical industries, automatic machinery and the methods of mass production, wireless, printing, Newton, Darwin, and Einstein, and thousands of other things and men too famous and familiar to catalogue."

"What is the result? In spite of an enormous growth in the population of the world, which it has been necessary to equip with houses and machines, the average standard of life in Europe and the United States has been raised, I think, about fourfold".[2]

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1) KEYNES, John M.: Essays in persuasion, New York, 1963 (W.W. Norton and Co. Inc.) p. 360.

2) Ibid, p. 363.

Possibly the first economist to incorporate a formal recognition of science into an extensive analytical framework of the economic growth process was Prof. J.A. Schumpeter.[1) In his study, Schumpeter regards each step in the process of economic growth as a "spontaneous and discontinues" change in the circular flow of economic life. Each of these steps is brought about by an innovation of which he differentiates five kinds.[2)]

"(1) The introduction of a new good - that is one with which consumers are not yet familiar - or of a new quality of a good.

(2) The introduction of a new method of production, that is one not yet tested by experience in the branch of manufacture concerned, and which by no means need be founded upon a discovery scientifically new, and can also exist in a new way of handling a commodity commercially.

(3) The opening of a new market, that is a market into which the particular branch of manufacture of the country in question has not previously entered, whether or not this market has existed before.

(4) The conquest of a new source of supply of raw materials or half-manufactured goods, again irrespective of whether this source already exists or whether it has first to be created.

(5) The carrying out of the new organization of any industry, like the creation of a monopoly position".

Taking these examples individually, it appears that the types of innovation mentioned under (1), (2) and (4) could have their roots in scientific discovery. It is conceivable therefore that, in given circumstances, scientific discoveries could trigger off commercial innovations of the type identified and thus contribute to the growth of the economy.

1.) SCHUMPETER, Joseph A.: <u>The theory of economic development</u>, New York, 1961 (Oxford University Press), p. 64.

2) Ibid., p. 66.

Even more explicit recognition of the economic rôle of science is given by Kuznets who accords to science the status of a "necessary condition"[1] of economic growth. Because man's control over nature is limited by his knowledge thereof, his ability to extend this control derives from scientific research. According to Kuznets a definite chain of events can be traced leading from scientific discovery, through technical invention, to commercial innovation and widespread economic application.[2] In keeping with Schumpeter, Kuznets does not maintain that science will automatically generate economic advance - only that economic advance, of the type that we have become accustomed to, cannot be conceived without it.

At least one author has ventured to estimate the net economic return on scientific research. This estimate was undertaken for the United States over a twenty-five year period from 1919 to 1954. To quote the author: "the annual return on research investment is estimated at 100% to 200%, i.e. 100% to 200%, per year average for a 25 year period".[3] The study in which the estimate is made makes fascinating reading and may be regarded as one of the pioneering efforts in this field. However, the findings of the author should not be regarded as conclusive, and the value of his exercise lies essentially therein that it poses an interesting hypothesis and serves as a point of departure for further investigations of a similar nature.

Ewell's hypothesis is that: "The United States has probably the highest economic growth rate among the highly industrialized countries of the world The United States is also distinguished by devoting the highest percentage of its national income to research and development. There is a definite

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1) KUZNETS, Simon: Six lectures on economic growth, New York, 1966 (The Free Press), p. 30.

2) Ibid., pp. 30 - 33.

3) EWELL, Raymond H.: "The rôle of research in economic growth", Chemical and Engineering News, vol. 33, no. 29, July 18, 1955, p. 2985.

correlation between these two facts. Research is a highly creative activity - it produces new products, creates new jobs and new industries, cuts cost of production, and makes a large contribution to our economic growth and our overall national welfare".[1)]

When the Ewell estimates are examined more closely however, it turns out that his figures are not the result of meticulous calculations based on accurate data, but rather approximations relying heavily on conjecture. For instance, in estimating the income from science Ewell argues; "No one has ever made a searching analysis of the effect of research on productivity, but one might speculate that out of the long term increase in productivity of 2.1% per year, at least 0.5% and more likely 1.0% or more, can be attributed to research. This is probably a conservative appraisal".[2)]

When compared with the 3 per cent annual rate of growth for the economy as a whole research is held responsible for between 16 and 33 units out of every 100 units of growth.

This assumption, together with a further assumption regarding the time lag between expenditure on research and the benefits that it yields, constitute the basis of the Ewell estimate of a 100 per cent to a 200 per cent rate of return on research expenditure. We will have occasion to return to these estimates again in the following Section.

Since these estimates were made in 1955, further research has thrown much more light on the impact which science has on the economic system.

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1) Ibid., p. 2980.

2) Ibid., p. 2983.

This research has proceeded along two lines:- a study of (i) the macro-economic characteristics of growth with particular emphasis on the rôle of technology; and (ii) empirical studies of the direct economic effects of science. In the following two Sections each of these two lines of investigation will be dealt with in turn.

2.2 Economic growth and technological advance

The study of economic growth at the macro-economic level is one of the most enlightening fields of enquiry from the point of view of the present dissertation with its interest in the overall economic impact of science. And while it has not yet provided a satisfactory basis for estimating an economic return to science, it has brought us closer to a more realistic estimate than has been possible in the past.

In this Section we will deal with attempts at estimating the contribution of various forces to overall economic growth. We will start with a brief discussion of the type of economic model, viz an aggregate production function, which is implied in the analysis, and then proceed to an examination of the different estimates. The Section will be concluded with a short review about the possible contribution of science.

A. The aggregate production function and the concept of the "third factor"

In any attempt to assess the magnitude of various growth factors in overall economic advance, the use of an aggregate production function is virtually indispensable. Economists are still striving to find a production function which adequately represents reality and yet retains sufficient mathematical simplicity to reveal the essential growth features.

Of those available the Cobb-Douglas function seems to have become the most popular, even though its simplifying assumptions places severe limitations on its practical value. For the present purposes however, the Cobb-Douglas function provides a suitable point of departure.

Essentially the Cobb-Douglas function has the following form:

$$O_t = S (K_t^a L_t^b) T_t \quad \text{———————} \quad (1)$$

Where:

O_t = potential aggregate output during a particular period,

K_t = capital stock available during the period,

L_t = labour input during the period,

T_t = level of technology prevailing in the economic system during the period,

S = scale parameter,

a = marginal returns to capital,

b = marginal returns to labour.

The following assumptions are made:

(i) There are constant returns to scale, i.e. $a + b = 1$.

(ii) All technological change is neutral in that it does not affect the ratio of a to b.

(iii) Under the assumption of marginal product equal to marginal revenue, the elasticities of production, a and b, are equal to the shares of K and L in national income.

It may be pointed out that the aggregate production function consists of two classes of variables <u>viz</u>:

(a) "Quantity inputs", which are the measurable inputs of the production factor labour and capital, and;

(b) "Quality inputs", which are the inputs of immeasurable forces influencing the quality of the inputs of labour and capital, and which is generally described as the "level of technology".

Note that:

$$T_t = \frac{O_t}{S (K_t^a L_t^b)} \quad \text{———————} \quad (2).$$

Whereas the "quantity inputs" can be readily calculated from given statistical sources the "quality inputs" cannot, as they mostly represent economic forces for which no adequate measure has as yet been conceived, and for which no statistical data are consequently available. Forces constituting "quality inputs" are:

(a) Improvements in the ability of the labour force.

(b) Improvements in the technical capabilities of capital stock.

(c) Rationalization of production methods and improvements in organization.

(d) Economies accruing from increases in the scale of production.

(e) Shifts in the structure of the economy and consequently changes in the pattern of employment from low productivity to high productivity sectors.

The combined influence of "quality inputs" taken together are frequently called the "third factor" because it is not directly measurable.

In practice the extent of the "third factor" as a source of economic growth is calculated as a residual after allowing for the influence of the other growth forces. This calculation is performed by transforming equation (1) into a formula representing annual percentage change. By taking logs and differentiating, equation (1) becomes:

$$\frac{\Delta O_t}{O_t} = \frac{a\Delta K}{K_t} + \frac{b\Delta L}{L_t} + \frac{\Delta T}{T_L} \qquad \text{———} \quad (3)$$

In this equation ΔK can be calculated on the basis of a series of capital stock estimates; ΔL can be determined from a time series of labour inputs such as total hours worked; and ΔO can be calculated on the basis of a series of deflated figures for some measure of aggregate output. The parameters a and b are pre-selected on the basis of the elasticities of production of labour and capital which are estimated as the share of labour and capital in national income in the base year of calculation. $\Delta T/T$ is then calculated as the residual:

$$\frac{\Delta T}{T_t} = \frac{\Delta O}{O_t} - \left(a \frac{\Delta K}{K_t} + b \frac{\Delta L}{L_t} \right) \quad (4)$$

Most of the data on economic growth presented later on in this Section have been calculated with the aid of a model of this nature.

In a recent review of aggregate production functions, Nelson [1] has pointed out that economic analysis has arrived at a point where it is possible to compute various components of $\Delta T/T$ by using an extension of the Cobb-Douglas function.

Essentially Nelson argues that, on the basis of work done by economists such as Solow and Denison, it is possible to find values for the following model.[2]

$$\frac{\Delta O}{O_t} \frac{\Delta A}{A_t} + \left(b \frac{\Delta L}{L} + b \lambda L \right) + \left(a \frac{\Delta K}{K} + a \lambda K + a \lambda K \left(\Delta \bar{n} \right) \right) \quad (5)$$

Where: $\frac{\Delta A}{A}$ = Rate of improvements not directly associated with either labour or capital, such as improvements in the allocation of resources and better management practices.

λL = Rate of improvement in the average quality of the work force.

λK = Rate of improvements in the quality of the capital stock.

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1) NELSON, Richard R.: "Aggregate production functions and medium range growth projections", American Economic Review, vol. LIV, no. 5, September 1964, pp. 575 - 606.

2) Ibid. p. 587.

(Solow[1] termed this "embodied" technological progress indicating that investment is required to embody the improvements in the production process).

$\bar{n}$ = average age of capital stock.

The value of $\bar{n}$ is derived from the following formula:[2]

$$\bar{n} = 1 - \left(\frac{\Delta K}{K} + \acute{o} \right) \quad (\bar{n}_t - 1)$$

Where: $\acute{o}$ = depreciation (exclusive of obsolescence).

From equations (4) and (5) it follows that:

$$\frac{\Delta T}{T_t} = \frac{\Delta A}{A_t} + b\lambda L + a\lambda K + a\lambda K(\Delta \bar{n}) \quad \text{———} \quad (6)$$

This model as expressed in equation (5) has a number of advantages over the simpler Cobb-Douglas function. First it isolates from the residual those economic forces which are directly calculable. And second it gives recognition to investment for replacement which cannot be separately taken into account in the Cobb-Douglas function in its original form. In the original form the Cobb-Douglas function is interested in nett investment only. The model as formulated in equation (5) is sensitive to gross investment as well in that it shows the effect of investment for replacement (on the average age of the capital stock).

Unfortunately most of the empirical studies of economic growth which have been undertaken to date have not attained this level of sophistication and we will have to be content with data in a somewhat more aggregated form.

In the following Sub-section data will be presented on the extent to which labour inputs, capital inputs and the third factor have contributed to

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1) SOLOW, Robert M.: "Technical change and the aggregate production function", Review of Economics and Statistics, vol. 39, August, 1957, pp. 312 - 320.

2) NELSON, Richard R.: op. cit., p. 585.

economic growth in various countries and for various periods of time. More detailed analysis of the composition of the third factor will be undertaken in the Sub-section after that.

B. The contribution of labour inputs, capital inputs and the third factor to economic growth in various countries

Tables I - IV give details of the contribution of labour inputs, capital inputs and the third factor to economic growth in various countries and for various periods of time. Tables I - III cover an advanced group of countries such as the United States, Western Europe and Japan, while Table IV deals with a number of Latin American countries.

TABLE I

ESTIMATED CONTRIBUTION OF INCREASES IN LABOUR FORCE, CAPITAL AND THE THIRD FACTOR TO ECONOMIC GROWTH IN THE U.S.A.[1)]

Country	Period	Annual rate of increase in national income %	Increase in national income due to :			Index of contribution (Annual increase in national income = 100)		
			Increase in labour %	Increase in capital %	Rôle of third factor %	Increase in labour	Increase in capital	Rôle of third factor
United States of America	1929-1957	2.93	0.90	0.43	1.60	31	15	54

Table I is based on an analysis undertaken by Denison for the United States of America. This analysis was made for two sub-periods, viz, 1909 to 1929 and 1929 to 1957. As may be expected the estimates for the latter

1) DENISON, Edward F.: The sources of economic growth in the United States and the alternatives before us, New York, 1962 (Committee for Economic Development), p. 266. Data have been re-arranged to comply with the concepts used in this paper.

period are more accurate than the estimates for the former, and the present discussion will be concerned with the latter period only.

According to Denison's calculations, real national income in the U S A increased by 2.93 per cent per annum during the period 1929 - 1957. Of this growth rate a portion of 1.57 percentage points could be attributed to increases in labour adjusted for quality change, 0.43 percentage points could be attributed to increase in capital without allowing for quality change; while 0.93 percentage points could be attributed to the third factor, in other words, all other forces not accounted for by the two inputs specified.

It will be noted, however, that Denison's calculations for the increase in labour inputs allow for an improvement in the quality of labour. This practice has not been generally followed and it is more customary to allow all improvements in the quality of inputs to accumulate in the residual. Consequently, in order to render the Denison figures more useful to the present discussion, it is convenient to re-arrange them in the same form as the other data. When written in this way the values appear as in Table I.

Table II is taken from an article by Aukrust[1)] based on a study by the United Nations: Economic Commission for Europe and by an investigation undertaken by the Central Bureau of Statistics of Norway. Table III is based on a further analysis[2)] by Denison, this time of a more recent date, and dealing with economic growth in nine advanced countries. In this table, as in Table I, Denison's data were reorganized to comply with the concepts used in this dissertation. Table IV is based on an analysis[3)]

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1) See Table II for relevant reference.

2) See Table III for relevant reference.

3) See Table IV for relevant reference.

TABLE II

ESTIMATED CONTRIBUTION OF INCREASES IN LABOUR FORCE, CAPITAL AND THE "THIRD FACTOR" TO ECONOMIC GROWTH IN VARIOUS COUNTRIES OF WESTERN EUROPE, SCANDINAVIA, CANADA, ISRAEL AND JAPAN[1)]

Country	Period	Annual rate of increase in gross domestic product %	Increase in gross domestic product due to:			Index of contribution (Annual increase in gross domestic product = 100)		
			Increase in labour %	Increase in capital %	Role of "third factor" %	Increase in labour	Increase in capital	Role of "third factor"
Belgium	1949-1954	3.6	0.4	0.7	2.5	11	20	69
	1954-1959	2.3	-0.1	0.8	1.6	- 4	34	70
Canada	1949-1959	4.3	1.5	2.1	0.7	35	49	16
Netherlands	1949-1954	4.9	1.0	1.2	2.7	20	25	55
	1954-1959	4.1	0.8	1.7	1.6	20	41	39
Norway	1949-1959	3.7	0.1	1.3	2.3	3	35	62
Sweden	1949-1959	3.4	0.3	0.6	2.5	9	17	74
United Kingdom	1949-1959	2.5	0.4	0.9	1.2	16	36	48
France	1949-1954	4.8	0.1	0.9	3.8	2	19	79
	1954-1959	4.1	0.1	1.2	2.8	3	29	68
Italy	1949-1954	6.4	1.1	0.9	4.4	17	14	69
	1954-1959	5.7	0.6	1.0	4.1	10	18	72
Western Germany	1950 -1954	8.3	1.3	1.4	5.6	15	17	68
	1954-1959	6.6	1.0	2.1	3.5	15	32	53
Israel	1952-1958	9.8+	2.3	3.6	3.9	23	37	40
Japan	1950-1958	7.9	1.7	3.2	3.0	21	41	38

\+ Net national product.

1) Calculated from data presented in: AUKRUST, ODD: "Factors of economic development, a review of recent research", Productivity Measurement Review, February 1965, No. 40, p. 19.

TABLE III

ESTIMATED CONTRIBUTION OF INCREASES IN LABOUR INPUTS, CAPITAL INPUTS AND THE "THIRD FACTOR" TO ECONOMIC GROWTH IN VARIOUS ADVANCED COUNTRIES IN AMERICA, EUROPE AND SCANDINAVIA[1)]

Country	Period	Annual rate of increase in national income %	Increase in national income due to:			Index of contribution (Annual increase in national income = 100)		
			Increase in labour %	Increase in capital %	Role of "third factor" %	Increase in labour	Increase in capital	Role of "third factor"
United States	1950-1962	3.32	0.63	0.83	1.86	19	25	56
	1950-1955	4.23	0.88	0.98	2.37	21	23	56
	1955-1962	2.67	0.45	0.73	1.49	17	27	56
Belgium	1950-1962	3.20	0.33	0.41	2.46	10	13	77
	1950-1955	3.25	0.48	0.43	2.34	15	13	72
	1955-1962	3.18	0.23	0.40	2.55	7	13	80
France	1950-1962	4.92	0.16	0.79	3.97	3	16	81
	1950-1955	4.77	0.18	0.71	3.88	4	15	81
	1955-1962	5.03	0.15	0.84	4.04	3	17	80
Germany	1950-1962	7.26	1.26	1.41	4.59	17	20	63
	1950-1955	9.93	1.88	1.20	6.85	19	12	69
	1955-1962	5.39	0.83	1.57	2.99	15	29	56
Italy	1950-1962	5.96	0.56	0.70	4.70	9	12	79
	1950-1955	6.30	0.96	0.57	4.77	15	9	76
	1955-1962	5.71	0.28	0.80	4.63	5	14	81
Netherlands	1950-1962	4.73	0.63	1.04	3.06	13	22	65
	1950-1955	6.00	0.90	1.18	3.92	15	20	65
	1955-1962	3.83	0.44	0.94	2.45	12	24	64
United Kingdom	1950-1962	2.29	0.31	0.51	1.47	14	22	64
	1950-1955	2.32	0.68	0.10	1.54	29	5	66
	1955-1962	2.27	0.05	0.80	1.42	2	35	63
Denmark	1950-1962	3.51	0.45	0.96	2.10	13	27	60
	1950-1955	1.58	0.33	0.91	0.34	21	58	21
	1955-1962	4.92	0.54	0.99	3.39	11	20	69
Norway	1950-1962	3.45	-0.09	0.89	2.65	- 3	26	77
	1950-1955	3.69	0.17	1.14	2.38	5	31	64
	1955-1962	3.27	-0.28	0.72	2.83	- 9	22	87

1) DENISON, Edward F.: Why growth rates differ, Washington D.C., 1967 (The Brookings Institution) pp. 298, 302, 304, 306, 308, 310, 312, 314 and 316.

TABLE IV

ESTIMATED CONTRIBUTION OF INCREASES IN LABOUR INPUTS, CAPITAL INPUTS AND THE "THIRD FACTOR" TO ECONOMIC GROWTH IN VARIOUS LATIN AMERICAN COUNTRIES[1)]

Country	Period	Annual rate of increase in gross domestic product %	Increase in gross domestic product due to:			Index of contribution (Annual increase in gross domestic product = 100)		
			Increase in labour %	Increase in capital %	Role of "third factor" %	Increase in labour	Increase in capital	Role of "third factor"
Argentine	1940-1945	2.9	-	1.3	1.6	-	45	55
	1946-1951	3.4	1.6	1.4	0.4	47	41	12
	1955-1959	1.7	1.4	0.9	-0.6	82	53	-35
	1960-1964	1.2	1.8	-	-0.6	150	-	-50
Brazil	1940-1945	3.2	1.0	0.9	1.3	31	28	41
	1947-1953	5.6	2.7	1.3	1.6	48	23	29
	1955-1959	5.6	2.4	1.5	1.7	43	27	30
	1960-1963	5.0	2.3	1.5	1.2	46	30	24
Chile	1940-1945	2.7	0.4	0.9	1.4	15	33	52
	1946-1953	3.9	1.5	1.0	1.4	38	26	36
	1955-1959	3.0	1.7	1.2	0.1	57	40	3
	1960-1964	4.0	2.4	0.7	0.9	60	17	23
Columbia	1940-1945	2.8	0.7	1.0	1.1	25	36	39
	1946-1953	5.2	1.8	1.1	2.3	35	21	44
	1955-1959	4.0	2.2	1.4	0.4	55	35	10
	1960-1964	4.5	1.9	1.1	1.5	42	25	33
Mexico	1940-1945	9.0	1.3	1.4	6.7	10	16	74
	1946-1953	5.0	2.5	1.3	1.3	50	26	24
	1955-1959	5.7	2.2	1.5	2.0	39	26	35
	1960-1964	6.2	2.1	1.3	2.8	34	21	45

1) Calculated from data presented in: BRUTON, H.J.: Productivity growth in Latin America, American Economic Review, December 1967, Vol. LVII, No. 5, pp. 1103-1104.

by Bruton of the contribution of various growth forces to economic advance in Latin America.

From these tables it appears that the third factor nearly always plays a significant rôle in the economic growth of various countries although its importance varies from country to country and period to period. The available data show that in general, it accounts for a larger share of economic growth in a more advanced group of countries than in certain Latin American countries.

In the case of the Latin American countries less than half show third factor influences which are greater than 35 units out of a 100 units of growth, while in the case of the more advanced countries all the values, with the exception of Canada in Table II, are greater than 30. Moreover, more than half the values for the more advanced countries in Table II, and nearly all the values for more advanced countries in Table III, are greater than 60, while in the case of the Latin American countries, one only (and possibly an exception) has a value greater than 60.

We may draw the conclusion from these figures, that in the advanced countries, the third factor would account for anything from one third to four fifths of economic growth, while in the case of the less advanced countries this influence would be less, accounting for something like one fifth to one third.

We may now pose the question: What has all this got to do with the economic impact of science? The answer to this lies in a further breakdown of the third factor, which will now be discussed.

C. The third factor and the rôle of science

The third factor accounts for all growth forces not explicitly accounted for in the measures of inputs of labour and capital. The growth influence of science would therefore constitute part of the third factor. But its share is difficult to assess. Of late much progress has been made in determining the relative magnitude of the various growth forces contributing thereto, and while no clear cut estimate on the economic impact of science has yet emerged, it is nevertheless of value to examine, in some detail, that which we know.

The pioneer in this field of enquiry is Denison who, with his two penetrating works already referred to, has given us some adventurous but closely reasoned estimates of a whole number of growth forces. Apart from calculating the increase in labour and capital inputs (and, in the case of labour, allowing for the effect of more man years, shorter hours, changes in the composition of the labour force, and education), Denison also sets out to measure the influence of economies of scale, improved allocation of resources, reduction in the age of capital equipment, and a few other (relatively minor) sources of growth. Only after calculating the effects of all of these, does he determine a residual - which then represents the effects of the advance of knowledge, lags in the application of knowledge (other than that already accounted for by reduction in the age of capital equipment) and errors and omissions.

The results of Denison's investigations are presented in Tables V and VI where they are arranged in a manner[1] reflecting the particular interests and purpose of this thesis.

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1) Table V is based on the classification adopted by AUKRUST, op. cit. p. 21, while Table VI has been drawn up with this example in mind.

TABLE V

ALLOCATION OF GROWTH RATE OF TOTAL REAL NATIONAL INCOME OF THE U.S.A. AMONG THE SOURCES OF GROWTH, 1929 - 1957[1)]

	Growth rate in percentage points %	Index of relative contribution to growth (2.93% = 100)
Increased employment (net effect of more man-years, shorter hours, and changes in the composition of the labour force)	0.90	30.7
Increased use of capital	0.43	14.7
Education and advance of knowledge[2)]	1.25	42.7
Better educated labour force	0.67	22.9
Advance of knowledge	0.58	19.8
Economies of scale	0.34	11.6
Growth of national market	0.27	9.2
Independent growth of local markets	0.07	2.4
Other factors	0.01	0.3
Change in lag of application of knowledge	0.01	0.3
Reduced waste of labour in agriculture	0.02	0.7
Industry shift from agriculture	0.05	1.7
Restrictions against optimum use of resources	-0.07	- 2.4
Overall growth rate	2.93	100.0

1) DENISON, Edward F.: op. cit. p. 266.

2) Aukrust uses the heading "Education and research", but the more general term "Education and advance of knowledge" is preferred here.

TABLE VI

ALLOCATION OF GROWTH RATE OF TOTAL REAL NATIONAL INCOME OF VARIOUS COUNTRIES AMONG THE SOURCES OF GROWTH 1950-1962[1)]

	AMERICA		EUROPE												SCANDINAVIA			
	U.S.A		BELGIUM		FRANCE		GERMANY		ITALY		NETHERLANDS		U.K		DENMARK		NORWAY	
	Growth rate in percentage points	Index of relative contribution to growth	Growth rate in percentage points	Index of relative contribution to growth	Growth rate in percentage points	Index of relative contribution to growth	Growth rate in percentage points	Index of relative contribution to growth	Growth rate in percentage points	Index of relative contribution to growth	Growth rate in percentage points	Index of relative contribution to growth	Growth rate in percentage points	Index of relative contribution to growth	Growth rate in percentage points	Index of relative contribution to growth	Growth rate in percentage points	Index of relative contribution to growth
1. Increased employment (net effect of more man years, shorter hours and changes in the composition of the labour force).	0.63	19	0.33	10	0.16	3	1.26	17	0.56	9	0.63	13	0.31	14	0.45	13	-0.09	- 3
2. Increased use of capital	0.83	25	0.41	13	0.79	16	1.41	19	0.70	12	1.04	22	0.51	22	0.96	27	0.89	26
3. Education	0.49	15	0.43	13	0.29	6	0.11	2	0.40	7	0.24	5	0.29	13	0.14	4	0.24	7
4. Advance of knowledge	0.76	23	0.76	24	0.76	16	0.76	10	0.76	13	0.76	16	0.76	33	0.76	22	0.76	22
5. Changes in the lag in the application of knowledge and other residual factors.	-	-	0.08	3	0.75	15	0.84	12	0.89	15	0.44	9	0.03	1	-0.28	- 8	0.18	5
Reduction in age of capital	-	-	. .	.	. .	.	0.04	1	. .	.	. .	.	. .	.	0.04	1	0.04	1
Other (including errors and omissions)	-	-	0.08	3	0.75	15	0.80	11	0.89	15	0.44	9	0.03	1	-0.32	- 9	0.14	4
6. Economies of scale	0.36	11	0.51	16	1.00	20	1.61	22	1.22	20	0.78	17	0.36	16	0.65	19	0.57	17
Growth of national markets	0.30	9	0.33	10	0.44	9	0.63	9	0.55	9	0.48	10	0.22	10	0.35	10	0.38	11
Income elasticities	-	-	0.11	4	0.49	10	0.91	12	0.60	10	0.23	5	0.09	4	0.23	7	0.12	3
Independent growth of local markets	0.06	2	0.07	2	0.07	1	0.07	1	0.07	1	0.07	2	0.05	2	0.07	2	0.07	2
7. Improved allocation of resources	0.29	8	0.51	16	0.95	19	1.01	14	1.42	24	0.63	13	0.12	5	0.68	19	0.92	27
Contraction of agricultural inputs	0.25	7	0.20	6	0.65	13	0.77	11	1.04	17	0.21	4	0.06	2	0.41	12	0.54	16
Contraction of non-agricultural self-employment	0.04	1	0.15	5	0.23	5	0.14	2	0.22	4	0.26	6	0.04	2	0.18	5	0.23	7
Reduction of international trade barriers	. .	.	0.16	5	0.07	1	0.10	1	0.16	3	0.16	3	0.02	1	0.09	2	0.15	4
8. Other forces, separately calculated but grouped together here	-0.04	- 1	0.17	5	0.22	5	0.26	4	0.01	-	0.21	5	-0.09	- 4	0.15	4	-0.02	- 1
Overall growth rate	3.32	100	3.20	100	4.92	100	7.26	100	5.96	100	4.73	100	2.29	100	3.51	100	3.45	100

SOURCE: 1) DENISON, Edward F.: Why growth rates differ, pp. 298, 302, 304, 306, 308, 310, 312, 314, 316.
The index of relative contribution to growth has been recalculated and differs in certain cases from the figures in the original text.

As may be expected Denison sounds a cautionary note, with regard to these estimates. "I have tried to break down this rate among its sources. The results, ... are rough estimates; their derivation required some strong assumptions, ... and they can be improved by additional research. They are by no means offered as definitive or precise. However, I do think that the estimates to which they contribute of the yield of possible steps to alter the future growth rate, provide better perspective than was previously available".[1] With this in mind we may proceed.

Three forces identified by Denison are of particular relevance here. They are: "education" which accounts for anything from 2 to 15 units out of every 100 units of economic growth, "advance of knowledge" which accounts for 10 to 33 units out of every 100 units of economic growth, and changes in the lags of application of knowledge and other residual factors, which account for minus 8 to 15 units out of every 100 units of economic growth.

To interpret these values we have to determine the true meaning of each term and how it was measured.

As far as the concept of "better educated labour force" (or simply "education" as Denison termed it), is concerned, this covers all spheres of formal education ranging from junior to senior school and on to the university level. To calculate the economic value of education, Denison assumes that it is equal to the additional income which an employee can command as a consequence of his higher educational status. This is calculated as the income differential between the educated and non-educated within a given age group.

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1) DENISON, Edward F.: "Measuring the contribution of education (and the residual) to economic growth", in: ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT, STUDY GROUP IN THE ECONOMICS AND EDUCATION: <u>The residual factor and economic growth</u>, Paris, 1964 (OECD) . p. 14.

From this we may gather that Denison's measure of the economic impact of this category includes the effects of post-graduate education as well, and if we argue further that post-graduate education is frequently associated with a certain amount of research, it may be claimed that part of the growth of the economy attributed to education is, in fact, attributable to formal scientific research. This may be termed the "educational link" of the relationship between scientific research and economic growth.

As far as the concept advance of knowledge is concerned, Denison points out that: "It includes, of course, what may be termed technological knowledge - knowledge concerning the physical properties of things, and of how to make, combine, or use them in a physical sense. It also includes what I call "managerial knowledge", that is, knowledge of techniques of management, construed in the broadest sense, and of business organization".[1]

In Table V it will be seen that "advance of knowledge", according to Denison, contributed 0.58 percentage points to growth in the United States over the period 1929-1957. While over the period, 1950-1962, as shown in Table VI, it contributed 0.76 percentage points. For the other countries covered in Table VI 0.76 percentage points is given throughout as the magnitude of the effect of "advance of knowledge". This immediately strikes one as unrealistic - but it stems from the particular procedure adopted by Denison to estimate the impact of this growth force.

In his estimates, Denison starts off by calculating a residual for each of the nine countries. This, (which we will term the first residual) covers

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1) DENISON, Edward F.: Why growth rates differ, Washington D.C., 1967 (The Brookings Institution) p. 280.

the effects of "advance of knowledge" together with "changes in the lag in the application of knowledge". (The latter category comprises: "reduction in the average age of capital" and "other" - such as errors, omissions and improvements in the lag between best and average practice). He then assumes that the residual calculated for the United States measures accurately the contribution of "advance of knowledge" in that country. This assumption also implies that in the United States there was no important change in the "lag" in the application of knowledge.

Next Denison assumes that: "Because knowledge is an international commodity I should expect the contribution of advances of knowledge - as distinct from changes in the lag - to be about the same size in all the countries examined in this study".1) Consequently, he attributes 0.76 percentage points of economic growth in each country to "advance of knowledge". This value he then subtracts from the first residual obtained for each country (as defined above) and obtains an "ultimate residual" which he then views as the result of "changes in the lag in the application" as well as all other errors and omissions.

He does recognize however that: " ... this second assumption can be in error insofar as there is a correlation between (a) differences in the 'mix' of the economies with proportions, scale, and the like, and (b) differences in the rate at which knowledge pertinent to production in different situations advances".2) Which may be succintly rephrased as follows:- different economies will have different knowledge requirements and will call forth different patterns of advances in knowledge. But, unfortunately, Denison's investigation stops short of probing this aspect further.

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1) Ibid., p. 282.

2) Ibid., p. 286.

Herein lies the great disadvantage of using the Denison calculation for any estimate of the economic impact of science and which limits our use of them to the point where we are virtually back to the impressionistic level. Denison's study does have the value however, that it draws attention to the "international commodity" nature of knowledge and that it emphasizes the difference between "advance of knowledge" and changes in the lag in the application of knowledge - thereby focussing attention on the latter also and underscoring its importance.

For the purpose of this thesis it is perhaps better to return to the full contribution of residual sources (including "advance of knowledge" and changes in the lag in application) to the growth rate, and draw our conclusion from this figure. The relevant data are summarized in Table VII.

According to the information at our disposal, "advance of knowledge" and the changes in the lag in the application of knowledge (including errors and omissions) together account for anything from 10 to 45 units out of every 100 units of the growth in various countries. Our estimate of the aggregate economic impact of science has to be made in terms of this theoretical maximum and has to take account of the following:

(a) These estimates are calculated as residuals and therefore include the accumulation of errors made in the calculation of all the other growth forces.

(b) "Advance of knowledge" covers a wide range of categories ranging from the outcome of formal research and development efforts in the natural and social sciences to empirical knowledge gained from "factory floor" experience and other practical situations.

(c) Much of what is included under the concept of "advance of knowledge" amounts, in a particular country, to what might be called the importation of foreign technology.

TABLE VII

CONTRIBUTION OF RESIDUAL SOURCES (INCLUDING ADVANCE OF KNOWLEDGE, BUT EXCLUDING EDUCATION) TO GROWTH RATES OF TOTAL NATIONAL INCOME 1950-1962

(In percentage points)

Country	Contribution of residual
United States	0.76
Belgium	0.84
France	1.51
Germany	1.56
Italy	1.65
Netherlands	1.20
United Kingdom	0.79
Denmark	0.44
Norway	0.90

Source: DENISON, Edward F.: Why growth rates differ, op. cit. p. 281.

In view of these limitations a general estimate of the aggregate economic impact of science would appear to be probably less than 20 units out of every 100 units of growth in the case of the advanced countries. In the lesser developed countries this maximum would be appreciably lower.

This estimate is somewhat more conservative than the Ewell estimate for the United States of between 16 and 33 units.

Before concluding this Section one final comment is called for. The above analysis ignores entirely the effects of quality improvement brought about by science, in other words those improvements to final products, not reflected in monetary terms. Also ignored is the greater choice available to consumers as a result of the wider variety of final goods. These are much neglected aspects which should be allowed for when an impression is formed about the aggregate economic impact of science.

2.3 The economic impact of science - direct empirical evidence

Various studies have already been undertaken to test the hypothesis, or to prove, that research and development activities have a direct economic impact. A selected number are presented below.[1)]

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1) Studies not discussed here but which are relevant to the matter being investigated include, *inter alia*:

- JEWKES, J., SAWERS, D., and STILLERMAN, R.: *The sources of invention*, op. cit.
- SCHMOOKLER, J.: *Invention and economic growth*, Oxford, 1967 (Oxford University Press).
- PECK, Merton J.: "Inventions in the postwar American aluminum industry" in: *The rate and direction of inventive activity : economic and social factors*, (the proceedings of a conference) Princeton, 1962, (Princeton University Press), pp. 279 - 298.
- ENOS, John L.: "Inventions and innovation in the petroleum refining industry", in: *The rate and direction of inventive activity : economic and social factors*, op. cit. pp. 299 - 322.
- MUELLER, Willard F.: "The origins of the basic inventions underlying du Pont's major product and process innovations 1920 to 1950", in: *The rate and direction of inventive activity : economic and social factors*, op. cit. pp. 323 - 360.
- COMANOR, N.S.: "Research and technological change in the pharmaceutical industry", *Review of Economics and Statistics*, vol. XLVII, no. 2, May 1965 pp. 182 - 190.
- Another study of major importance, although taken from the military field is reported in: SHERWIN, C.W. *et al* : *First interim report on project hindsight (summary)*, Washington, D.C., 1966 United States Department of Defense, Office of the Director of Defense Research and Engineering). This report deals with the scientific origins of various defense innovations and stresses the time lag of 5 to 10 years frequently encountered in effectively "fitting in" the results of highly applied research into an operational system, and 20 years for the results of undirected research.

These studies differ from the studies of aggregate economic growth discussed in the previous Section in that in those studies the interest in scientific research and development was incidental, while in the studies discussed in this Section, the interest in scientific research and development constitutes the central theme.

A. Intra-plant study

The first study to be reported here is an intra-plant study undertaken by Hollander[1)] of the sources of increased efficiency in the Du Pont Rayon Plants in the United States.

In this study increased efficiency is defined as a reduction in the unit cost in the rayon production process. The observed reduction in unit costs is attributed to two major causes. Firstly, "technical change" which is defined as improvements in the raw materials or in the production process, and secondly, "economies of scale" which come about through expansion in plant activities.

The category "technical change" is then divided into two categories, viz "major technical change" and "minor technical change". Hollander regards a "major technical change" as one which was; "considered 'difficult' to accomplish by men 'skilled in the pertinent arts' prior to the successful development". A "minor technical change" he regards as "one which was considered simple to accomplish".[2)]

The distinction between major and minor technical changes are particularly relevant to the discussion in hand in that the former are essentially derived from formal research and development. As Hollander puts it:

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1) HOLLANDER, Samuel: The sources of increased efficiency: a study of Du Pont rayon plants, Cambridge, Massachusetts, 1965 (M I T Press).

2) Ibid., p. 52.

"the 'major' technical changes were for the most part dependent upon internal research conducted formally by Rayon Research, although technical assistance personnel also contributed substantially".1) On the other hand: "minor technical changes encountered in our study were in the most cases developed internally by Du Pont. Some important contributions were made by equipment manufacturers (although much of the work in these cases involved co-operative ventures), and by suppliers of raw materials. The larger part of the minor changes were developed at the plants themselves by personnel intimately concerned with current operations, whose function was often to keep existing operations trouble free, rather than by Rayon Research and other formal research groups".2)

Table VIII and IX summarize the results of Hollander's investigations. Table VIII gives the contribution of various factors to the reduction of unit costs. In Table IX the contribution of each factor is expressed as an index. This table shows that in four out of the five plants investigated, "major technical changes" made some contribution to reduction in unit costs. In one case it was responsible for approximately half the savings observed, while in the other three cases it contributed nearly 20 units out of every 100 units of cost reduction.

From this study we may conclude that under certain circumstances scientific research can contribute to increased efficiency by its effect on a reduction in unit costs. While this contribution was not very large its frequent occurrence in the cases studied underscores its significance.

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1) Ibid., pp. 196 - 197. As may be gathered, Rayon Research is the name of a formal research establishment.

2) Ibid., p. 204.

TABLE VIII

CONTRIBUTION OF VARIOUS FACTORS TO REDUCTION IN UNIT COSTS AT FOUR DU PONT RAYON PLANTS

(Figures expressed in cents)[1]

Name of plant	Period	Reduction in unit costs due to: Major technical change	Minor technical change	Economies of scale	Other factors	Reduction in unit costs
Old Hickory	1929-1951	7.03	23.78	3.83	1.31	35.96
Spruance I	1932-1950	6.47	26.88	-	1.12	34.47
Spruance II	1937-1951	-	2.86	4.89	-0.24	7.51
Spruance III	1938-1952	6.10	5.26	0.54	-	11.90
Spruance II a	1948-1952	0.64	3.18	-	-	3.82

TABLE IX

CONTRIBUTION OF VARIOUS FACTORS TO REDUCTION IN UNIT COSTS AT FOUR DU PONT RAYON PLANTS

(Figures expressed as index of contribution)

Name of plant	Period	Index of contribution of various factors to reduction in unit costs: Major technical change	Minor technical change	Economies of scale	Other factors and rounding error	Reduction in unit costs = 100
Old Hickory	1929-1951	19	66	11	4	100
Spruance I	1932-1950	19	78	-	3	100
Spruance II	1937-1951	-	38	65	-3	100
Spruance III	1938-1952	51	44	5	-	100
Spruance II a	1945-1952	17	83	-	-	100

1) Source: HOLLANDER, op. cit. pp. 74, 88, 98, 108 and 116.

B. Industry-wide studies

At the industry-wide level three interesting studies are available concerning the correlation between expenditure on research and development and various measures of economic performance.

(a) United States chemical firms

The first of these studies was undertaken by Minasian and was based on a limited sample of eighteen United States chemical firms from which information was obtained for the years 1947-57. Minasian's analysis is of the cross-section type and was conducted in accordance with rigorous statistical standards. He sets out to test the general hypothesis: "The greater the research and development expenditures, measured in several ways to be described below, the greater is the subsequent rate of growth in the productivity of a firm".[1)]

Minasian also tests certain alternative hypotheses viz:

(i) That profitability is the determinant of the level of research and development expenditures and the determining factor in increase in productivity.

(ii) Growth in productivity is best explained by investment in plant and equipment which investment is also necessary to embody new technology.

(iii) Economies of scale are important contributors to growth in productivity and also provide for a more effective use of research and development resources.

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1) MINASIAN, Jora R.: "The economics of research and development". The rate and direction of inventive activity: economic and social factors, (the proceedings of a conference), Princeton, 1962 (Princeton University Press) p.100.

(iv) Monopoly pricing allows a firm to improve its ratio between outputs and input and increase the level of productivity.

As a result of these correlation studies, Minasian claims: "We can conclude from this study that, beyond a reasonable doubt, causality runs from research and development to productivity, and finally to profitability. With the possible exception of differential monopoly power (the test of its influence was not conclusive) no other factor tested was able to compete effectively with, or even to complement substantially, the relationships found between the above variables".[1]

(b) British manufacturing industry

A second correlation study which is of interest, is one undertaken by Freeman and Evely of the association between growth, profitability and research ratios in 95 firms in British industry. This analysis covers the period 1949-1959 and includes: 44 firms in general engineering, 22 firms in the chemical and allied industries, 12 firms in electrical engineering, and 17 firms in steel manufacture.

Although a certain positive association between the three variables studied emerged for chemical manufacture and general engineering, i.e. firms ranked at the extreme positions in the sample, namely the top 5% and the bottom 5%, the degree of correlation found to exist in the other cases provided inconclusive support for strong positive association. The general conclusion reached was that: "Additional research and development appears to make only a limited contribution to additional growth. The greater part of the differences between firms in rates of growth and profitability are due to other factors

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1) Ibid, p. 95.

than differences in the amount of research and development".[1]

(c) Various sectors of United States industry

The third correlation study which is of interest is the one undertaken by Mueller of the correlation between expenditure on research and development and number of patents registered for various sectors of American industry, and covering research and development expenditure in the years 1958, 1959 and 1960. The industries covered were; aircraft and metals, chemicals, machinery, petroleum, food and other. In each case the research and development expenditure for the industries in each group is compared to the patents received by the said industries three years later. The findings of this investigation are summarized in Table X.

TABLE X

CORRELATION BETWEEN EXPENDITURE ON RESEARCH AND DEVELOPMENT AND A NUMBER OF PATENTS*[2]

INDUSTRY	1960	1959	1958
1. Aircraft and metals	.71	.65	.49
2. Chemicals	.81	.82	.90
3. Machinery	.95	.90	.88
4. Petroleum	.95	.90	.89
5. Food	.99	.92	.94
6. Other	.89	.86	.91

* The research and development expenditure used in the correlation is that for the years shown while the number of patents are those for the years 1964, 1963, and 1962, respectively.

1) FEDERATION OF BRITISH INDUSTRIES: Industrial research in the manufacturing industry 1959-60, London, 1961 (Federation of British Industries), pp. 43-49.

2) Source: MUELLER, Dennis C.: "Patents, research and development, and the measurement of inventive activity", Journal of Industrial Economics, vol. XV, no. 1, November 1966, pp. 28, 29 and 31.

Furthermore, it may be mentioned that Mueller broke the total expenditure on research and development down into its constituent parts, i.e. basic research, applied research, and development, and compared each of these with the number of patents registered. In the case of most groups the correlation between expenditure on development on the one hand and the number of patents on the other, was of the same magnitude as the correlation between total expenditure on research and development and the number of patents registered, and higher than the correlation between expenditure on applied research and the number of patents, as well as the correlation between expenditure on basic research and the number of patents registered. In the case of one group of industries the highest correlation existed between expenditure on applied research and the number of patents registered.

In general, however, Mueller concludes that: "This suggests that an economically meaningful relationship does exist between what goes into the inventive process, as measured by R and D, and what comes out as measured by patents".[1)] This is a far cry from saying that a correlation exists between what goes into the inventive process (as measured by research and development) and what comes out as value for the industry (as measured in terms of economic growth), but it does point in that direction rather than in the opposite, and in this sense it could be called upon to support the hypothesis that a positive link can exist between scientific research and economic growth.

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1) Ibid., p. 34.

C. Impact on foreign trade

The final two empirical studies to be cited here, deal with the economy at a macro-level, and examine the links between the intensity of research and development efforts and export performance. Both studies deal with the United States, but in the case of the second one some interesting comments concerning Germany, the United Kingdom and France are made as well.

These studies have been motivated largely by a thorough re-investigation of the theory of international trade as expounded and developed successively by Smith, Ricardo, Mill, Marshall, Heckscher and Ohlin - the newer thinking being that the basis of international trade, namely comparative advantage, can be generated by research and development and need not arise from resource endowments.

As Hufbauer introduces this concept: "Bananas are grown in tropical regions, and coal is mined where lush forests once stood. But scientific progress has created a class of industries not dependent upon climate or natural resources for their location. The manufacture of most synthetic materials - plastics, synthetic rubbers, and man-made fibres - belongs to this class. Because of its independence from nature's endowments, the 'foot-loose' synthetic materials industry provides a challenging study in international trade".[1)]

(a) Impact of science on foreign trade - Study I

The first study was undertaken by Keesing[2)] and was aimed at determining the association between the research and development

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1) HUFBAUER, G.C.: Synthetic materials and the theory of international trade, London, 1966 (Gerald Duckworth and Company Ltd.) p. 13.

2) KEESING, Donald B.: "The impact of research and development on United States trade", Journal of Political Economy, vol. 75, no. 1, February, 1967, pp. 38 - 45.

effort of various economic sectors and their competitive trade performance. To this end eighteen sectors of the United States economy were identified and a measure of research performance calculated for each. This measure was then compared to the export performance for each of these sectors. Export performance was calculated as the ratio between United States exports in each sector and exports by the Group of Ten.[1)] A linear correlation coefficient of 0.66 and a Spearman coefficient of rank correlation of 0.78 was obtained. Both of these are statistically significant.

In order to investigate the exclusiveness of expenditure on research and development as a determinant of international trade performance, Keesing then investigated a number of other relationships to determine whether strong causality does not originate in other factors as well.

Four factors are investigated. They are;

(i) capital requirements, (ii) natural resource requirements, (iii) labour skill requirements, and (iv) economies of scale.

Keesing finds that the relationship between capital requirements and trade performance is strongly negative and suggest that expenditure on research and development and capital requirements are competitive. This is an interesting observation which incidentally agrees with a similar conclusion drawn by Minasian in the article reported earlier.[2)] As far as natural resource requirements are concerned, Keesing points out that even if one omits from the original correlation study those sectors of the economy which are obviously reliant on available natural resources, the previously observed high correlation between

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1) In addition to the U.S.A. these include Belgium, Canada, France, Italy, Swede Japan, Switzerland, West Germany and the United Kingdom.

2) Sub-section B.(a)

research and development effort and export performance still holds.

In examining labour skill requirements as a causal factor in export performance, a fairly high correlation is obtained between the latter and the following categories of employment;

(i) scientists and engineers employed in research and development,
(ii) scientists and engineers employed outside research and developmen
(iii) other professions.

The following two categories show an extremely weak, and possibly even negative, association with export performance;
(iv) skilled manual workers, (v) semi-skilled and unskilled manual workers.

Finally Keesing reports that there seems to be a positive association between the economies of scale and research and development effort, but that economies of scale cannot rival research and development for "explaining" the export performance of various sectors. In the case of the Minasian study reported earlier, no significant correlation was found to exist between economies of scale and productivity.

(b) Impact of science on foreign trade - Study II

The second study to be cited here was undertaken by Gruber, Mehta and Vernon.[1)]

In this study nineteen sectors of the United States economy are differentiated. For each of these, two measures of research effort were calculated and the ranks of these then compared with two measures of export performance. Research effort was measured both in terms of (i) total expenditure on research and development as percentage

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1) GRUBER, William, MEHTA, Dileep, and VERNON, Raymond: "The research and development factor in international trade and international investment of the United States industries", Journal of Political Economy, vol. 75, no. 1, February, 1967, pp. 20 - 37.

of sales, and (ii) scientists and engineers in research and development as percentage of total employment. The measures of export performance were:- (i) exports as percentage of sales; and (ii) excess of exports over imports as percentage of sales. A Spearman rank correlation coefficient was then calculated for the first measure of research effort and the two measures of export performance in turn, and subsequently between the second measure of research effort and the two measures of export performance in turn. In this way four measures of correlation were obtained, each of which were found to be highly significant in a statistical sense.

As a study of this nature could possibly yield high correlation coefficients merely because of the correlation in size of efforts, a further study was undertaken in which the export performance was contrasted with the performance on the domestic market. The result of this study shows that: ".... the five industries with the strongest research effort accounted for 72.0 per cent of the nation's exports of manufactured goods, though they were responsible for only 39.1 per cent of the nation's total sales of such goods. The same five industries were also responsible for 89.4 per cent of the nation's total R & D expenditures and 74.6 per cent of the company-financed R & D expenditures. The five industries concerned therefore represent both the heart of U.S. export strength in manufactured products and the heart of its industrial research effort".[1)]

The authors then go on to point out that similar high correlation coefficients are obtained between United States research and development efforts for various sectors and export performance in those sectors by the United Kingdom and Western Germany. However, when

1) Ibid., pp. 24 - 25.

the export figures for France are used in the study their correlations disappear. The authors come to the conclusion that the export strength of the United Kingdom and Western Germany, like that of the United States, lie in their research intensive sectors, while, in the case of France, other comparative advantages apply.

D. Concluding remarks

The studies cited in this Section virtually all lend support to the view that research and development is a significant factor in the economic process. With respect to its contribution to reduction in unit costs in existing manufacturing industries, as illustrated by Hollander; with respect to its contribution to productivity as illustrated by Minasian; and with respect to its contribution to international competitive ability, as illustrated by Keesing, and by Gruber *et al.*, the research and development factor has always emerged as a significant variable (and more significant than any of the other factors for which a statistical test was undertaken). The only exception noted was that of the study of British manufacturing industries.

None of these studies however, bring us closer to a more accurate measure of the aggregate economic impact of science, and one gains the impression that such a measure is, as yet, beyond the scope of economic analysis.

2.4 Current views on science as an economic force

A. The notion of a direct link between scientific research and economic growth

The general evidence on the economic impact of science has led to arguments for the strengthening of science because of its overall economic influence and has also led to the view that under certain circumstances science may be regarded as a tool of economic policy.

Symptomatic of this attitude is the remark by Aukrust that: "I am tempted to conclude: If I were given the economic dictatorship of a country, charged with the task of ensuring a maximum rate of growth, I would be prepared to risk my posthumous fame by betting heavily on education and research - under the motto: 'Mind over machine'."[1)]

So also the Second Ministerial Meeting on Science, held under the auspices of the Organisation for Economic Co-operation and Development during October, 1963, dealt with the question of science and economic growth as one of the three substantive items of the agenda, and came to the conclusion that: "Education and research may thus be regarded as basic factors in the process of economic growth, with investment in capital equipment being relegated to an intermediate rôle".[2)]

In the communiqué which was issued immediately following the meeting, reference is made to the policy implications of the said link and it is stated, inter alia, that: "The Ministers recognized the growing importance of science and technology in the economic and social development of the Member countries. They therefore stress the importance of establishing effective links between science policy and economic policy."[3)]

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1) AUKRUST, Odd: "Factors of economic development - a review of recent research", Productivity Measurement Review, February, 1965, no. 40, p. 22.

2) MESTHENE, Emmanuel G. (Editor): Minister's talk about science, Paris, 1965, (Organisation for Economic Co-operation and Development), p. 95.

3) Ibid., p. 132.

It may be seen, therefore, that even though the notion of a link between scientific research and economic growth is of fairly recent origin, it is already making its influence felt in the highest policy making circles. Furthermore it is fast becoming part of the "conventional wisdom" on science and the danger exists that an over-simplified view of the link could lead to policy measures which are unwarranted.

As an example of such a view being put forward in influential circles, we may take the following remark by a witness testifying before a congressional committee on the proposed State Technical Services Act in the U.S.A. "For a number of years now, dollars going into R and D have been increasing faster than the gross national product. I am convinced that this lack of keeping pace is, at least partially due to a lack of transfer from one field to another - from those generating and developing them to those who could use them".[1] This statement implies two things. First, that the witness believes in an immense causative power of science to generate an economic impact, and second, that the pace of the economy is naturally linked with the pace of science, and that any difference between the two is indicative of some deficiency.

B. Some reservations

It is interesting to contrast these attitudes with the sobering reservations of economists recently reflecting on the relationship between scientific research and economic growth.

Kuznets, for instance, in re-examining the chain of events leading from scientific discovery through technical invention and widespread economic

1) U.S. CONGRESS, HOUSE, COMMITTEE ON INTERSTATE AND FOREIGN COMMERCE, SUB-COMMITTEE ON COMMERCE AND FINANCE: State Technical Services Act, 1965, Hearings on H.R. 3420, Washington, D.C., 1965 (U.S. Government Printing Office) p. 127.

application points out that: ... "there is a bottleneck relationship between the successive phases - from the scientific discovery to the spread of an innovation. Each scientific discovery is potentially the base for a wide variety of inventions (which is one major reason why discoveries are not patentable), but not all those possible inventions are reproduced. Each invention is a candidate for innovation, but only a small proportion of inventions is adopted. Each innovation is a candidate for widespread use, but only a limited proportion is extensively used and can then be characterized as major innovations".[1)]

Another commentator, Blackett, also expresses grave reservations about the relationship and quotes empirical evidence to suggest that in Britain at least, this link is extremely tenuous. "Recent studies", he claims; "particularly by the Organisation for European (sic) Co-operation and Development (O.E.C.D.), have revealed some very important facts about the relationship, or sometimes the lack of it, between R and D expenditure and economic growth. For instance, in 1962 Britain spent 2.2% of her Gross National Product (GNP) on R and D compared with 1.4% for France and 1.3% for West Germany. Here is a European league at the top of which Britain is! In marked contrast, Britain's economic output per man grew between 1955 and 1964 at the rate of only 2.6% per year, compared with 4.4%, 4.7% and 8.8% for France, West Germany and Japan respectively. Here we are at the bottom! For instance, Japan's productivity has grown 3.5 times faster than Britain's, but she has spent only a little over half as much on R and D. So clearly. mere expenditure on R and D does not lead inevitably to economic growth".[2)]

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1) KUZNETS, op. cit., p.31

2) BLACKETT, P.M.S.: Technology, industry and economic growth, The thirteenth Fawley Foundation Lecture, Southampton, 1966, (University of Southampton), p. 8.

No discussion covering misgivings about the relationship between science and economic growth would be complete without reference to the works of Williams or Carter.[1] In a number of studies they have meticulously questioned the existence and the nature of the said relationship and have come to the conclusion that very special circumstances must exist in the economy ere scientific research activities can serve as effective economic inputs. After an empirical study covering various sectors of the British economy Williams observes: "The mere quantity of industrial research is by no means an infallible guide to growth potential. Industrial research will not create growth potential unless the right problems are chosen, solved, and taken through the later stages of development and application.

The choice of problems is critical and involves much more than a judgement from the researchers that a problem is interesting and likely to produce a solution. It must be a problem relevant to the production and marketing situation and the management and financial capacity of the firm".[2]

We observe therefore that on theoretical grounds (as argued by Kuznets), on the basis of empirical studies at the macro-economic level (as presented by Blackett) and on the basis of empirical studies at the micro-economic level (as presented by Williams and Carter) strong reservations have been expressed about the existence of an effective and exploitable link between scientific research and economic growth.

In view of the apparently conflicting attitudes on the relationship between scientific research and economic growth we may quite well ask what our views should be and how these would influence further studies and policy-making.

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1) CARTER, C.F. and WILLIAMS, B.R.: Industry and technical progress, London, 1957 (Oxford University Press). Investment in innovation, London, 1958 (Oxford University Press). Science in industry, London 1959 (Oxford University Press).

2) WILLIAMS, Bruce: "Country case studies on research development and economic growth: United Kingdom", International Social Science Journal, vol. XVIII, no. 3, 1966, p. 417.

C. <u>Hypothesis about the link between scientific research and economic growth</u>

Firstly, incontrovertible theoretical arguments can be formulated that science (whether performed domestically or abroad) has some sort of influence on the economy. Scientific research has the effect of extending the range of innovational opportunities available to industrialists by making them aware of a greater variety of the features of nature than would have been known had scientific research not rendered them comprehensible. Examples may be quoted of new materials which are made by restructuring matter, i.e. by breaking it down to its rudimentary sub-molecular parts and then building it up again; and of new sources of energy, such as atomic energy, which is unleashed by disturbing the fundamental arrangement of atoms. Such technology would have been impossible without science and much of the economic benefit derived therefrom may be directly attributed to scientific research.

In the more economically advanced countries these scientific possibilities are so habitually exploited that the rate of growth of the economy may be said to have become largely influenced by the insights provided by research and development. According to this argument research and development becomes a necessary condition for economic expansion at the rate that we have become accustomed to.

Secondly, the above arguments should not be taken to imply that a generally valid, direct and quantifiable relationship can be determined between the inputs of research and development, and the rate of technological advance in a given economy. Apart from the various bottlenecks occurring <u>en route</u> from a scientific discovery to a commercial innovation some of the results of science find application abroad, while some of the innovations at home are derived from research performed elsewhere.

From a policy point of view this means that no economic grounds can be found for a general exhortation to governments to indiscriminately appropriate more and more funds to "science" . From the point of view of the study of the economics of science the implication is that it would be unwise to continue searching for a simplistic model reflecting the aggregate economic impact of science, or an overall rate of return on scientific expenditure. Another model for visualizing the economic influence of science must be thought of. Among other things this model must take account of the international flow pattern of scientific and technical information and the technological requirement of the economy at various stages of growth.

Thirdly, in view of the fact that science is regarded as a necessary condition for economic growth it may be accepted that under very special circumstances a direct link may exist between scientific research and economic growth. This would probably only occur if:

(i) The technological capability of industry (or of government departments in those areas where the government has assumed responsibility for economic action) is at least of the same order of sophistication as that of the scientists producing the relevant knowledge. If this condition is not met, industry and government will not be able to share the new insights gained through science and exploit these within their own field of interest.

(ii) Industry has attained the minimum critical size required to carry out the costly and risk bearing task of bringing a scientific discovery to technical fruition and commercial viability.

However, even if these requirements are met, it could quite easily occur that the rate of research activity outstrips the rate of application in a particular country, in which case the necessary condition for economic progress is more than adequately met and the economic gains from additional research become progressively smaller.

In addition to the two conditions mentioned above two further conditions must apply therefore before research in general will have a significant economic impact. These are:

(iii) Science-based industries must play a dominant rôle in the country's economic life and be among the leaders of the country's industrial expansion.

(iv) These science-based industries must be faced with problems of a scientific nature which at the same time also constitute areas of significant scientific interest.

If all of these conditions prevail it may be said that it is a feature of the country's economy that a direct link exists between scientific research and economic development. Very few countries in the world today meet these unique requirements - an estimate of less than half a dozen would probably be high. It is highly unlikely that any semi-advanced countries, or countries with labour surplus economies even remotely meet these requirements.

Fourthly, because it is known that science can act as an economic stimulant under certain circumstances, all countries would be justified in seeking ways and means to profit from science. This would seem a far more difficult task for the under-developed and semi-advanced countries than for the highly developed nations. It is not possible at this stage to recommend specific actions for the lesser advanced group of countries but in principle these actions would amount either to an increase in the national scientific level, or to an increase in the capacity for industry to absorb the fruits of science, (or, of course, to both these alternatives). Depending on the particular state and need of the economy specific measures could entail:

(i) encouraging scientific and technical education,

(ii) establishing central government sponsored research laboratories,

(iii) encouraging the establishment of co-operative research organizations within industry,

(iv) encouraging the establishment of in-house research facilities in industry,

(v) creating organizations to encourage and facilitate the transfer of scientific and technical information.

Fifthly, it may be pointed out that, on economic grounds, few countries can escape the responsibility of performing at least some research. Even if it is argued that all technological knowledge can be imported from abroad it would seem unlikely that foreign technology can be effectively located and exploited without it being adequately evaluated at home. This would seem to call for a force of trained scientists, themselves working at the forefront of knowledge, but with an appreciation for the particular practical needs of their own country, who can monitor and evaluate relevant scientific developments abroad.

Finally, as stated earlier, the need exists for formulating a conceptual model of the impact of science on the economy, and which is not a simplistic model portraying a direct link between science and that part of economic growth caused by research. The model required would be a comprehensive model depicting the numerous economic influences of science, the patterns of international technological flows, and the technological requirements of an economy at various stages of development.

To this end detailed studies of the economic aspects of science in various countries are called for, to form an empirical base for later attempts at formulating a general model.

Concurrently herewith (and in order to effectively administer the actions discussed under the fourth point above), attention should be given to the development of policy-making and planning procedures which could identify a particular economy's scientific needs, and indicate appropriate action within an integrated overall policy framework for science and economics.

P A R T II

RESEARCH IN SOUTH AFRICA

3. SCIENCE IN SOUTH AFRICA, ITS BACKGROUND AND COMPOSITION

3.1 Review of developments

A. First steps towards science

Apart from the claim by Herodotus that a small fleet sent out from Egypt by Pharaoh Necho, travelled from the Red Sea southward and three years afterwards returned to Egypt through the Pillars of Hercules and the Mediterranean[1)] thereby implying a rounding of the Cape of Good Hope from the east circa 610 B.C., we have little evidence that the southern tip of Africa had any exposure to the great western civilisations before 1487 A.D. when Bartholomew Dias discovered the sea way around the Cape for Portugal.

However, it was not until a century and a half later that the first settlement of western civilisation was established at the southern tip of the African continent. The date, all too familiar with South Africans, was 1652, and the unwilling bearer of western ideals, Jan van Riebeeck. The date is interesting, if merely because of coincidence, for it preceded by five years the founding of the Academia del Cimento in Italy, and preceded by fourteen years the founding of the Royal Society in Britain.[2)]

The establishment of the settlement at the Cape occurred therefore simultaneously with the scientific revolution which was taking place in Britain and Europe at the time. It is not strange therefore, to find scientists calling at the Cape hardly three decades after the settlement had been founded.

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1) WALKER, Eric: A history of Southern Africa, London, 1959, (Longmans) p. 1.

2) See Section 2.1.

(a) Early visitors[1)]

One of the earliest visits was that of the French Jesuit priest and Mathematician, Père Gui Tachard, who came to the Cape in 1685 and who, together with five other Roman Catholic priests, attempted to discover the true position of the Cape by means of astronomical observations. Other earlier visits recorded were those by Kolbe, also an astronomer, and Valentyn and Leguat.

During the regime of Ryk Tulbagh, and at his encouragement, the colony was visited by a number of men of eminence in science. Noteworthy among these were the Abbé de la Caille who stayed for two years and devoted his attention to the drawing of a star chart of the southern skies; and Sparrmann and Thunberg, who were sent by the famous Linnaeus from Uppsala, to gather specimens of plants and animals for his collection. The first notable contribution to ornithology in South Africa also dates from this period and was the work of the Frenchman, le Vaillant.

With the arrival of the British in the early eighteen hundreds a new stimulus was given to research, especially in the fields of geography and zoology. The British visitors Barrow and Burchell, and the German, Lichtenstein, may be noted. Further famous names included Pappé the Colonial Botanist and the first Professor of Botany at the South African College; Harvey, who started an exhaustive investigation of Cape flora; Herschell, who was responsible for the introduction of meteorological observations at the Cape; and Bain, who in 1828 discovered the first vertebrate fossil of the Karroo Beds - the

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1) Information on the early development of South African science is taken virtually exclusively from: COUNCIL FOR SCIENTIFIC AND INDUSTRIAL RESEARCH, Science in South Africa, Pretoria, 1949, (CSIR).

so-called "Blinkwater Monster" - and whose discovery paved the way for the subsequent palaeontological finds which have placed South Africa on the scientific map of the world.

We could continue referring to individual scientists and their activities, but this would very soon become a cumbersome exercise giving little insight into those questions of scientific growth and expansion with which this dissertation is primarily concerned. The number and growth of scientific societies does, however, give us a better indication of the development of a scientific community in South Africa.

(b) Scientific societies

The first scientific society which was formed in South Africa, seems to be the South African Institution which was founded in 1827 and which in 1830 published the first volume of The South African Quarterly Journal. It appears that the institution experienced a number of problems and in 1832 decided to amalgamate with the South African Literary Society which had also been formed in 1827. The new society was named The South African Literary and Scientific Institution. But even this stronger and larger organization continued to experience difficulties and in 1835 the publication of the journal was suspended. In 1857 the Society ceased to function.

The next chapter in the development of scientific societies in South Africa, starts in 1877 when the South African Philosophical Society was founded. This society enjoyed good progress and by 1908 a charter was received whereby the society was re-constituted as the Royal Society of South Africa. Since its original foundation the society has published its Transactions annually.

In the meantime, in 1902, another non-specialist scientific society was formed in South Africa, namely The South African Association for the Advancement of Science, (commonly referred to as S_2A_3). The association too founded a journal, the widely known South African Journal of Science.

In 1909, the foundations were laid for yet another non-specialist scientific society when the Suid-Afrikaanse Akademie vir Taal, Lettere en Kuns was formed. The status of this society was changed to that of a statutory organization in 1921, and in 1942 it became the Suid-Afrikaanse Akademie vir Wetenskap en Kuns. The Akademie also publishes a series of journals - all in Afrikaans.

Apart from the non-specialist scientific organizations, South Africa has also seen the establishment of a number of specialist societies. Some of these were in existence before the non-specialist societies were formed, while others followed later. Of the oldest were the South African Association of Engineers and Architects founded in 1892, the Chemical and Metallurgical Society founded in 1894, and the Geological Society of South Africa founded in 1895. From the middle of the nineteenth century onwards various medical associations were formed in different parts of the country and the present South African Medical Association came into being in 1906. Another noteworthy development, was the change in emphasis of the Chemical and Metallurgical Society when it became known as the Chemical, Metallurgical and

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1) DART, R.A.: "The Associated Scientific and Technical Societies of South Africa", South African Journal of Science, vol. 60, no. 5, May, 1964, p. 130.

Mining Society of South Africa in 1903. In other words a move slightly away from basic science to technology.

From 1902 to 1946 the formation of at least eleven societies can be traced.[1)]

For an economist it is difficult to comment on the activities of these early scientists and institutions, for their actions contained so few of those manifestations which economics thrives upon. Essentially these early scientists were amateurs whose activities may be regarded as consumption in the economic sense, but with a very high cultural content. Their activities may be regarded therefore as privately chosen ends in themselves and not as means to achieve ends.

Not that the activities of these early scientists had no economic consequences. For had not Dr. W.J. Atherstone, the Geologist, who in 1867 identified the first diamond found in the Hopetown district, advised that further searches be made along the Orange and Vaal Rivers, we may well ask whether the "Star of Africa" (valued at R50,000) would have been found so soon afterwards and for how long the establishment of a diamond mining industry would have been delayed?

It is only when science becomes institutionalised and when it is held up as a means to achieve given social ends, that the economist finds it within his sphere of competence to comment on the allocation of resources for science. For it is at this stage that public funds usually become involved, whose commitment to science signifies the forfeiture of other social ends.

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1) COUNCIL FOR SCIENTIFIC AND INDUSTRIAL RESEARCH: Science in South Africa, op. cit. p.18.

B. The growth of the scientific establishment

(a) Musea and the first observatory

Before 1820, South Africa's rôle in the world of science was no more than an interesting collecting spot for overseas naturalists, and to some extent a new vantage point for astronomical observations. Of truly domestic science very little can be said. It was not until that date that serious work started on the domestic front. In that year the Royal Observatory at the Cape of Good Hope was established and the Reverend Fearson Fallows appointed as His Majesty's Astronomer.

In 1825 the governor of the Cape, Lord Charles Somerset, sanctioned the founding of the South African Museum, and appointed Dr. Andrew Smith as its Superintendent. It has been claimed that Dr. Smith may be regarded as the first individual who officially undertook scientific research in South Africa as a resident of the southern continent. After Smith's departure the South African Museum suffered a period of stagnation until it was founded anew in 1855 and constituted by Act of Parliament in 1857.

In 1855, the Eastern Province Literary, Scientific and Medical Society formed the Albany Museum at Grahamstown. Between that date and 1907, the establishment of at least eight other museums can be recorded.[1)]

A more recent development, in this connection, and especially of interest from a technological point of view, is the establishment in 1962 of a Museum for Science and Industry of South Africa.[2)]

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1) Ibid., p. 15.

2) SCHOONRAAD, Murray: "New science museum for South Africa", South African Journal of Science, vol. 60, no. 7, 1964, p. 209.

However, after its enthusiastic beginnings and first thrust of expansion, it seems to have lost much of its impetus after the resignation of its first curator.

(b) Institutions of higher education

Turning to higher education, the year 1829 saw the establishment of the first institution of this nature at the Cape, namely the South African College. This first college initially concentrated on school work but slowly advanced its status and by the 1870's university education dominated its activities. Between 1848 and 1874 various institutions of a similar nature were founded in the different parts of the country.

The first university to be established with the power to confer degrees, was the University of the Cape of Good Hope, created in 1873. In the course of time several colleges became incorporated in the University of the Cape of Good Hope, while the majority of the dual nature colleges mentioned above reverted to predominantly school work only. Eventually the University of South Africa was created in 1916 to take over the functions of the University of the Cape of Good Hope as an examining body. At the same time independent university status was granted to the South African College, which became the University of Cape Town. In that year the Victoria College, founded as a Gymnasium in 1866, became the University of Stellenbosch.

Records show that from an early date science, especially at the University of Cape Town, played a very important part in university activities. The first Professor of Physics, Roderick Noble was appointed in 1855, while a chemistry laboratory was made available in 1881 and a physics laboratory in 1895.[1]

An early list[2] of staff publications contained approximately eight pages of reference to scientific papers and two to the fields of education, economics, languages, philosophy and history.

At present there are nine independent residential universities in South Africa, and five university colleges. In addition to these there is also the University of South Africa which conducts correspondence courses and which acts as examining body to the said university colleges. While the universities played a fairly significant part in the establishment of science in South Africa, it will be seen that their present participation has dwindled somewhat.[3]

(c) Government bodies

Apart from the museums and universities, the second half of the nineteenth century saw the establishment of a number of mission orientated scientific organizations within the government sector. Among these may be classified the Durban Botanical Gardens which, it is on record, grew tea in 1851 and which were probably founded some years before; the Cape Government Herbarium founded in 1863; the Geological Commission of the Cape of Good Hope established in 1896 and which later, together with the Geological Survey of

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1) WALKER, Eric: The South African College and the University of Cape Town, 1929 Cape Town, (Cape Times Limited), pp. 46 and 52.

2) RITCHIE, W.: History of the South African College 1829 - 1918, 1918, Cape Town, (T. Maskew Miller), pp. 731 - 742.

3) See Sub-section 3.2 C.(a)

Transvaal, became the Union Geological Survey; the Marine Biological Survey which was established in the Cape in approximately 1896, and later became the Division of Sea Fisheries of the Department of Industries; the Cape Meteorological Commission established in 1874; and the Allerton Veterinary Laboratory which was built just outside Pietermaritzburg in 1898.

With the founding of Union in 1910, a strong drive toward mission orientated research could be identified and a number of organized research establishments were created within the government departments of Agriculture, of Forestry and of Mines. Of these, the Department of Agriculture has always played a very significant part in South African science in terms of the vast amount of research which it performs. At one stage, for instance, the Division of Chemistry within the Department of Agriculture was given full responsibility for all State chemical services and in recognition of this status was named the Division of Chemical Services. Even today, the normal budget of the Department of Agricultural Technical Services exceeds that of any other research organization in the country.[1)]

As far as the general promotion of science and its administration by the Government is concerned, a first step in this direction was the formation of a Research Grants Board under the Department of Mines and Industries[2)] in 1918. The function of this Board was

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1) FOURIE, L.J., VAN WYK, R.J.: Uitgawe aan natuurwetenskaplike navorsing en ontwikkeling binne die staatsektor in Suid-Afrika, gedurende die finansiële jaar 1966/67, Pretoria, 1968, (Wetenskaplike en Nywerheidnavorsingsraad).
VAN WYK, R.J. and FOURIE, L.J.: Expenditure on research and development in the natural sciences in South Africa during the calendar year 1966 and the financial year 1966/67, Pretoria, 1968, (Council for Scientific and Industrial Research).

2) KINGWILL, D.G.: South African Council for Scientific and Industrial Research, Pretoria, 1953, (mineograph).

to administer funds for research by experienced scientists and post-graduate students at universities. These funds were mainly derived from the Carnegie Corporation in the United States. In 1933 the Board was transferred to the newly created Department of Commerce and Industries, but still continued to serve the whole of the scientific spectrum in South Africa. Soon after, in 1934, a South African Council for Educational and Social Research was formed under the chairmanship of the Minister of Education, solely for the purpose of administering the Carnegie funds.

However, the Research Grants Board continued to function until 1938, when it was reconstituted as the National Research Council and Board, and transferred to the Department of Education. Although, primarily concerned with the natural sciences, it retained also a small interest in the social sciences.

The next stage in the development of governmental machinery for encouraging and administering science, occurred after the war when two bodies were created to assume responsibility for research in the natural sciences and in the social sciences respectively. In 1945, the Council for Scientific and Industrial Research (CSIR) was created by an act of Parliament, and in 1946, the National Council for Social Research (NCSR) was created within the administrative framework of the Department of Education, Arts and Science.

The CSIR was given responsibility for all those fields in the natural sciences and technology for which specialist research organizations were not yet available, excluding the whole field of agricultural research which was already catered for by the Department of Agriculture. Among other things, the CSIR was responsible for administering the government funds for medical research but undertook very little of this research itself. In this connection it had to co-operate with the South African Institute for Medical Research and the medical schools attached to various universities in South Africa.

Originally the CSIR's link with parliament was through the Department of the Prime Minister. Afterwards it was transferred to the Department of Commerce and Industries and at present the Department of Planning acts as host to the Council.

With the establishment of the Atomic Energy Board by an Act of Parliament, early in the 1950's, and the announcement of its Research and Development Programme in 1959, nuclear research activities were, in the main, allocated to the new board.

In the meantime the need was felt for an advisory body on scientific matters, and the Advisory Council for Scientific Policy was established under the Department of Commerce and Industries. In 1962 this body was superseded by the Scientific Advisory Council falling under the Department of the Prime Minister.[1] The Scientific Advisory Council represents various disciplines in the natural sciences, as well as various government and semi-government departments.

The same year also saw the introduction of a Bill to provide for the establishment of the South African Inventions Development Corporation.[2]

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1) South African Digest; vol. 9, no. 31, 6th December, 1962, p. 2.

2) South African Digest; vol. 9, no. 6, 19th March, 1962, p. 9.

This organization would be empowered to acquire rights in inventions, to undertake inventions and to take out letters patent. The corporation would be closely associated with the CSIR and would inter alia take over from the CSIR the task of finalizing inventions based on scientific discoveries of the Council.

In 1964 the Scientific Adviser to the Prime Minister recommended the establishment of four new research councils to replace the existing structure[1]. These would be (i) a Council for Physical and Engineering Research (to supersede the CSIR), (ii) a Council for Biological Research, (iii) a Research Council for Earth Sciences, and (iv) an Atomic Energy Council. At present it is not clear when these recommendations will come into effect.

In 1968, the Minister of Planning, also announced the establishment of a Medical Research Council which would take over from the CSIR the responsibility for encouraging and administering medical research in South Africa. It was hoped to introduce the necessary legislation for the new body during the 1968 session of Parliament[2].

Finally, as far as social sciences is concerned, the formation of an autonomous Human Sciences Research Council has been announced to supersede the National Council for Social Research.

(d) Industrial research facilities

As far as industrial research is concerned, the Fuel Research Institute was established in 1930 with support from both the

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1) MÖNNIG, H.O.: Report of a study of scientific organization, Pretoria, 1964 (The Chairman of the Scientific Advisory Council and the Scientific Adviser to the Prime Minister), p. 109.

2) South African Digest, vol. 15, no. 21, 24th May, 1968, p. 4.

government and from the mining industry. At approximately the same time, two other co-operative research institutes were established without government support. They were, the Chamber of Mines Research Laboratory and the South African Sugar Association Experimental Station in Natal. A decade later, research undertaken in the Department of Chemistry at Rhodes University, Grahamstown, led to the establishment of a Leather Industries Research Institute in 1941, which later became associated with the Council for Scientific and Industrial Research. In 1947 South Africa saw the establishment of the Diamond Research Laboratory - a co-operative research organization without government sponsorship, and the Wattle Research Institute - a co-operative research organization with government sponsorship.

Apart from the Leather Industries Research Institute three other co-operative research institutes were formed under the auspices of the CSIR in the period 1945-1949. These are; the Fishing Industry Research Institute, the Sugar Milling Research Institute and the Paint Research Institute.

One of the latest developments in the growth of established research centres is the industrial laboratory providing in-house research facilities. It is more difficult to trace the origins of these, but from available records it would seem that the research organization of the United Tobacco Company, formed soon after the founding of the company in 1905, is one of the oldest.[1)] Other senior research establishments within the industry are the laboratories of Cullinan Refractories Limited which were established in approxi-

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1) COUNCIL FOR SCIENTIFIC AND INDUSTRIAL RESEARCH, INFORMATION DIVISION: Directory of scientific resources in South Africa, Pretoria, 1966 (CSIR), p. 156.

mately 1930 and which were re-organized in 1934, and the Natal Tanning Extract Company Limited whose research organization was founded in 1927.

The 1940's saw the development of quite a number of industrial research laboratories such as those of Agricura Laboratoria Limited in 1946; the Pretoria Portland Cement Company Limited in 1947; and the Metal Box Company Limited in 1949.

One gains the impression that the movement to establish industrial research laboratories has only just begun. For since 1950 even a larger number of new ones have been established or old ones re-organized. Examples here are: The Iron and Steel Industrial Corporation Limited, whose laboratory was established in 1952; Vereeniging Brick and Tile Company Limited, whose laboratory was established in 1954; the South African Coal, Oil and Gas Corporation Limited who created research facilities in 1958; and South African Paper and Pulp Industries Limited, whose research facilities in their present form were created in 1959.

A recent development of great interest was the establishment in 1968 of a technical centre in South Africa to serve the world-wide research and development needs (and other technical information requirements) of an international group of companies with headquarters in South Africa. This is the Stellenbosch based R.I. Technical Centre for the Rembrandt Group which has evolved from a Research and Development Department founded in 1960.[1]

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1) REMBRANDT TOBACCO CORPORATION (SOUTH AFRICA) LIMITED: <u>Chairman's review</u>, Stellenbosch, 1968.

Another new development also seems to be the establishment of contract research laboratories which undertake research and development projects at a fee on behalf of outside clients. The laboratories of Rand Mines Limited have been re-organized to perform this type of function, and at least one other has been recorded.

(c) Summary

To summarize therefore, we may divide the growth of the South African research establishment into three phases. The first phase, saw the creation of museums and university research facilities mainly around outstanding individuals who were concerned with science essentially because of their personal interest (and with little regard for its utilitarian value).

The second phase, saw the generation of research laboratories which were mission orientated and government controlled. This phase may be sub-divided into the creation of research facilities within the public service framework and the creation of research facilities outside the public service framework, such as the Council for Scientific and Industrial Research and the Atomic Energy Board.

The third phase commenced with the creation of co-operative industrial research institutes and has led on to the establishment of in-house research facilities and contract research laboratories. This phase is not yet completed and it can be expected that a large number of new industrial research laboratories will appear on the scene in the nearby future.

C. Present institutional structure

(a) Policy-making bodies

(i) The Scientific Adviser to the Prime Minister

This is the highest policy-making office in science in South Africa. The Scientific Adviser is an appointee in the Prime Minister's Office and is responsible for advising the Prime Minister on all aspects of promoting science, the training of scientists, conditions of employment, and all other matters pertaining to science.

In this position he transmits to the Prime Minister the recommendations of the Scientific Advisory Council of which he is also the Chairman.

(ii) The Scientific Advisory Council

The Scientific Advisory Council has no executive status and serves merely as a body which considers issues of scientific policy and makes recommendations to the Prime Minister.

The Council itself consists of two tiers, namely individual members, and Departmental representatives. The individual members are men of eminence in science drawn from all walks of life. Included within this category are heads of statutory research organizations, university professors, scientists in industry, and individual researchers of standing. This group consists of thirty-three members.

The departmental representatives on the Scientific Advisory Council are senior officials, usually the secretary of the department or some senior scientist. In this group there are eleven members.

To deal with certain questions relating to government involvement in science, a Central Co-ordinating Committee has been established consisting of those members of the Scientific Advisory Council who represent government departments and semi government agencies.

The Scientific Advisory Council therefore has the combined characteristics of a "society" of eminent men in science, selected on the basis of individual scientific achievements, and an inter-departmental committee on scientific matters.

The Council also has a number of specialised standing and temporary committees and, at the time of writing (October 1968), was entrusted with the following assignments:[1]

- The organization, planning and co-ordination of all scientific activities in the Republic;
- The establishment of a national register of scientists and technologists;
- The establishment of a manpower research and planning centre;
- School science teaching;
- Refresher courses for teachers;
- Facilities for post-graduate university training and research;
- Professional conferences for university lecturers;

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1) <u>Scientific Progress</u>, "The Scientific Advisory Council", vol, 1, no. 1, October, 1968, p. 2.

- Higher technical training;
- The training of engineers;
- The establishment of a salary research bureau;
- Studies of research and development costs.

(iii) Department of Planning

The executive arm of the government's scientific policy-making mechanism is located in the Department of Planning. This Department consists of three divisions, namely the Scientific Planning Division, the Economic Planning Division, and the Physical Planning Division. Each of these divisions is headed by a Deputy Secretary for Planning and the three of them fall under a Secretary for Planning.

The Deputy Secretary for Scientific Planning holds a dual position in that he is at the same time also Deputy Scientific Adviser to the Prime Minister. There exists therefore a well-forged link between representatives of the scientific community, the Adviser to the Prime Minister and the chief executive officer for scientific matters in the Department of Planning.

(b) <u>Research performers</u>

(i) The government sector

The government sector may be classified into (i) government departments, (ii) provincial administrations, (iii) statutory councils.

The numbers and importance of each of these may be discussed briefly.

(aa) Government departments

In the survey of expenditure on research and development undertaken by the CSIR and which will be discussed in more detail in Section 3.2, it was ascertained that eleven government departments in South Africa undertake research within their own research divisions. Three others support research in organizations other than their own.

Of the eleven government departments by far the largest is the Department of Agricultural Technical Services which controls ten fairly sizeable and specialized institutes.

(bb) Provincial administrations

All four provincial administrations in the Republic undertake research of one form or another - mostly in connection with nature conservation.

(cc) Statutory bodies

A number of statutory bodies have been formed in South Africa to undertake research. Three of these are classified within the government sector, namely the Atomic Energy Board, the Council for Scientific and Industrial Research, and the National Institute for Metallurgy. One other, the Fuel Research Institute, is classified with the business enterprise sector (in keeping with the practice followed in national accounting).

The largest of the statutory councils is the Council for Scientific and Industrial Research which controls thirteen national research institutes or laboratories and a number of independent research units.

(ii) Higher education sector

At present there are in South Africa fifteen universities and university colleges, nine of which are residential universities for white students, five of which are university colleges for non-white students, and one which is a correspondence university as well as an examining body for the colleges referred to.

In most of these institutions the research is limited to that which is undertaken within the various teaching departments, but at some universities, research units have been created (mostly financed by the Council for Scientific and Industrial Research, and in some cases by the Atomic Energy Board) around outstanding individual scientists. At other universities separate research institutes, such as the Bernard Price Institutes at the University of the Witwatersrand augment the on-campus research activities.

In the Cape Province the Universities of Cape Town and of Stellenbosch have co-operated in establishing a Southern Universities Nuclear Institute which is housed in its own buildings at Faure halfway between Cape Town and Stellenbosch.

(iii) Business enterprise sector

This is the sector about which the least is known concerning the present research establishment. Five different types of organizations falling within this sector are differentiated, namely:

(aa) In-house laboratories of public corporations.

(bb) In-house laboratories of private business enterprises.

(cc) Co-operative industrial research institutes supported by the Council for Scientific and Industrial Research.

(dd) Independent co-operative industrial research institutes.

(ee) Contract research organizations.

(aa) In-house laboratories of public corporations

From the CSIR's Directory of scientific resources in South Africa, and on the basis of information obtained during the survey of expenditure on research and development, which will be reported on in Section 3.2, five public corporations were identified possessing in-house research laboratories. Among these were some of the largest research facilities falling within the private sector.

(bb) In-house laboratories of private business enterprises

At least twenty six, and probably more, in-house laboratories of private business enterprises were in existence in 1966. Details of most are contained in the Directory of scientific resources in South Africa, but a few were encountered which are not specified in this source. It is conceivable that a number of others exist which have not been recorded but it is doubtful whether they would be very numerous.

A comprehensive list of the organizations noted, is provided in Appendix A.

(cc) Co-operative research institutes supported by the CSIR

Four co-operative research institutes are at present supported by the CSIR and are operative in as diverse fields as the fishing industry, the leather industry, the paint industry, and the sugar milling industry.

(dd) Independent co-operative research institutes

Seven institutes of this nature are on record. Six of these are companies registered under Article 21 of the Companies Act, while one is a statutory council.

(ee) Contract research institutes

As was pointed out earlier the development of contract research institutes is of very recent origin in South Africa. Seven such institutions have been brought to the author's attention but the existence of five could not be verified. On the other hand there could conceivably be more. Also it was not quite certain whether the institutes reported all performed true research and development and whether some do not limit their activities to other scientific services which are not necessarily of a research and development nature.

(iv) Private persons and non-profit institutions

This category includes ten museums, two observatories and two independent research institutes, namely the South African Institute for Medical Research and the Oceanographic Research

Institute at Durban. The institutions differentiated represent widely differing organizational types. Some have been created by government charter, some fall under the jurisdiction of local authorities, two are foreign owned and two are non-profit companies created under Article 21 of the Companies Act.

Also to be included in this category are at least one hundred individuals and learned societies who performed research with the aid of grants provided, mainly, by the CSIR. Finally, of course, there are the numerous individual investigators who pursue science for their own amusement and as true amateurs.

3.2 Expenditure on research and development in South Africa

A. Background to the survey of expenditure on research and development

The first complete statistical survey of expenditure on research and development in the natural sciences in South Africa was undertaken by the Industrial Economics Division of the CSIR, under the direction of the author, for the calendar year 1966 and the financial year 1966/67. Although still suffering from many shortcomings, this survey provides the first reliable estimate of expenditure on research and development in South Africa.

Before the 1966/67 survey, two earlier surveys were undertaken, namely for 1964/65 and 1965/66, but they were limited to the government sector and universities only and did not cover research within business enterprises.

An earlier survey of expenditure on research within business enterprises was attempted by the Bureau of Statistics at the request of and in consultation with the Industrial Economics Division of the CSIR for the financial year 1954/55. Unfortunately the results of this survey were completely unsatisfactory and did not contribute much to what is known today about the total expenditure on research and development in South Africa. What the 1954/55 survey did contribute was to show that a survey of research expenditure is not a simple matter, as it is not concerned with physical and readily definable entities, but rather with extremely esoteric human activities which have to be carefully described and classified. Consequently the Industrial Economics Division were able to plan the later surveys with very much more foreknowledge about problem areas.

In the general planning of the 1964/65, 1965/66, and 1966/67 surveys great reliance was placed on the manual[1] published by the Organisation for Economic Co-operation and Development, suggesting international standard practices for surveys of expenditure on research and development. This guide is commonly referred to as the Frascati Manual, after the locality where the first expert group met to draft the necessary recommendations.

Although the international recommendations were adhered to as far as possible in the South African survey, certain changes were adopted to render the survey results more useful for domestic requirements. These changes will be discussed in detail when the framework for research and development statistics is presented.

B. Framework for statistics on research and development

Before giving details about the extent and composition of research and development expenditure in South Africa, it is important to give some attention to the framework within which the data will be presented. Data on research and development have only recently[2] come to be regarded as of sufficient importance and practical value to justify their collection on a regular basis as standard statistics, consequently there is no long-standing tradition which dictates the manner in which they are to be gathered and presented.

As explained earlier, the only authoritative guide at present available is the Frascati Manual. The following discussion is based thereon and

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1) ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT: Proposed standard practice for surveys of research and development, Paris, 1963 (OECD).

2) General interest in R and D statistics only arose in the 1960's although a few countries have been gathering statistics for a longer period.

shows how the basic recommendations have been adapted to accommodate South African requirements.

(a) Research and development in relation to other scientific activities

One of the first (and, unfortunately, incorrect) assumptions which has frequently been made by those who have tried to calculate the extent of the research and development effort in particular countries, is that the aggregate research and development expenditure is merely the sum of the expenditures of the individual research and development organizations functioning within the country. In fact, however, it is both more than and less than this.

A typical research organization undertakes a wide variety of scientific activities falling outside the scope of research and development in the true and narrow sense of the concept. In other words, it does very much more than research and development proper. According to the Frascati Manual scientific activities may be classified into three major categories, namely:

(i) Research and development proper.
(ii) Research-related scientific activities.
(iii) Non-research scientific activities.

(i) Research and development proper

The main concern of this dissertation is with research and development proper. Unfortunately the Frascati Manual does not attempt to give a comprehensive definition of research and development proper and limits itself to definitions of the various sub-parts of the overall concept. However, for the purposes of the South African survey, the following definition was attempted and is based essentially on the definition of sub-parts as contained in the Frascati Manual.

Research and development may be defined as systematic, intensive, study, primarily aimed at the advancement of knowledge, whether to expose fundamental facts of nature, provide a factual background for the solution of practical problems, or provide the insight required for finalizing the design concept of new products, processes or practices to meet given functional or economic requirements.

This definition is somewhat extensive - which follows from the fairly wide field of activity which it has to encompass. However, the true nature of research and development will probably be more accurately described when the various sub-parts of overall research and development activity are defined later on in Sub-section 3.2 B (c).

(ii) Research-related scientific activities

As far as research-related scientific activities are concerned, these may be seen as those activities which are closely linked to research and development but which have too little of the component of innovation to be classified as research and development proper. Included in this category are all activities concerning communication amongst scientists, (including scientific publications) and all scientifically-linked education. Also included are data collection activitie not associated with particular research projects; and testing, standardization and calibration activities which are separately identifiable from research and development.

It is very difficult to give a general description of the activities included in this category. The <u>Frascati Manual</u> identifies them by means of examples, and for the present it may be assumed that this category is based more on convention than on definition.

(iii) Non-research scientific activities

Non-research scientific activities are activities which also draw on the services of scientific personnel but which are even further removed from the essential features of research and development proper than research-related activities. Again it is difficult to give a general yet lucid description of these activities and they are best described by means of example. Included in this category are routine testing and analysis of all kinds as well as a large variety of technical services.

Having identified those activities which are to be excluded from the category "research and development proper" it is now advisable to look at the various institutional breakdowns which may be employed in classifying research and development activities.

(b) <u>Institutional classification of research and development activities</u>

(i) Distinction between financiers and performers of research

When specifying research and development expenditure by type of institution either of two aspects may be emphasized: On the one hand, the source of financial support; and on the other hand, the institution undertaking the research work.

This is a rather important distinction and becomes particularly significant when the foreign sector plays an important part in the local research and development scene. For instance, if very much money is spent by foreign organizations on research and development within the country the figures for research and development performance will significantly exceed the figure for research and development financing. In other words, domestic expenditure on research and development will exceed national expenditure. Conversely, if the said country sponsors research abroad, the national expenditure on research and development will exceed domestic expenditure.

In this dissertation the main pre-occupation is with research and development performance rather than research and development financing. In principle therefore the statistics represent research and development activities undertaken within South Africa, including those financed from abroad, but excluding those undertaken elsewhere but financed by South Africa.

(ii) Classification of research organizations into the various sectors of the economy

According to the Frascati Manual the economy may be subdivided into four sectors for the purpose of classifying research and development organizations. These four sectors are as follows:

(aa) General government sector.

(bb) Business enterprise sector.

(cc) Private non-profit sector.

(dd) Higher education sector.

As this breakdown was used, and discussed, when the existing research establishment in South Africa was described in Section 3.1 C. it will not be examined any further. The various institutions covered in each category are listed in Appendix A.

(c) <u>The breakdown of research and development proper into various categories</u>

The total expenditure for research and development proper may be broken down in three further ways, each of which will now be discussed.

(i) Basic research, applied research and development

The breakdown of the category research and development proper into the sub-categories basic research, applied research and development is at the same time one of the most meaningless and one of the most useful classifications available for dealing with scientific activities.

It is virtually meaningless in communications between scientists because it is too general, and because most scientists would tend to be much more specific about their field of speciality or particular approach. However, for the non-scientist this classification is rather useful in that it provides some insight into the bewildering heterogeneous totality called "scientific research", and conveys some impression : ... "of the motives and working conditions of scientists".[1)] For this purpose it is also of some use to non-scientists who have to deal with scientific matters at the policy-making level.

The three categories may be defined as follows:

(aa) Basic research

Basic research is the name given to original investigations aimed at the advancement of scientific knowledge for which the research workers do not have

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1) KIDD, Charles V.: "Basic research - description versus definition", <u>Science</u>, vol. 129, no. 3346, 13 February 1959, p. 368.

a specific practical application in mind, even though they may be aware of its potential value.

Within this category the practice has arisen of distinguishing sometimes between what is called "free basic research" and "oriented basic research". Free basic research is said to cover the research activities of scientists who are free to choose their research area entirely according to their own inclination and value judgement. Oriented basic research is said to cover the activities of research workers whose research boundaries are somewhat more fixed although no specific practical problems have been delineated within these boundaries.

The question sometimes arises whether oriented basic research is not to be included with applied research. This is discussed below.

(bb) Applied research

This may be defined as investigations aimed at the advancement of scientific knowledge for which the research worker has a definite practical application in mind.

The definition of applied research therefore differs from the definition of basic research with respect to the objectives existing in the mind of the research worker. In the case of applied research the ultimate objective is that of applicability while this restraint does not exist in the case of basic research.

On the question of whether oriented basic research should not be included within the definition of applied research, it may be pointed out that although the area of enquiry may be delineated in the case of oriented basic research, there is no rigid discipline of applicability which constitutes the ultimate objective. In terms of the above definitions therefore, oriented basic research differs from applied research and is legitimately grouped together with free basic research.

(cc) Development

Development is more readily described with the aid of examples rather than in general terms. However, it may be described in general terms as: the action concerned with advancing the design concept[1)] of a product or process to the point where it meets specific functional or economic requirements. It is concerned largely, but not exclusively, with the non-routine adjustment problems which arise in the transition stage between research and the eventual industrial application and commercialization of research findings. It also covers improvement of existing products or processes if such action contains a large element of innovation. Development includes the erection of pilot plants and the construction of models and prototypes, but excludes industrial trouble-shooting not involving original investigation.

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1) The term "design concept" is used advisedly. The meaning intended is broader than the narrow interpretation attached to the term "design". What we intend to convey is "the overall concept in terms of which the design is executed".

As can be imagined, these definitions may possible give rise to a number of questions.

Quite rightly, Kidd[1] points out that there are two ways of defining the distinction between basic and applied research. The first is by means of "substance centred" definitions in which the dividing line is concerned with the features of the research itself. The second is by means of "investigator centred" definitions in which the dividing line is the attitude of mind of the research worker. The above definitions are all of the second kind. Consequently the statistical categories based on these definitions do not tell us much about the external features of the research included within each category and are not therefore of great value from a policy-making point of view.

Two points summarize the various views on the definition of basic and applied research and the use of these classifications as statistical categories. First, while the classification of research into the said categories does not in itself provide a useful classification for policy purposes, it does give, in a very general way, an indication as to whether the total research and development effort is related to national objectives or whether it is dissociated from utilitarian ends.

Second, the distinction provides those policy-makers who are non-scientists with some insight into the internal groupings of science, and in so doing generates an appreciation for the particular requirements of research, particularly basic research whose existence can hardly be justified in terms of utilitarian arguments.

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1) KIDD, Charles V.: op. cit. p. 369.

(ii) Scientific disciplines involved in research

Apart from the breakdown of research and development proper into basic research, applied research and development, there exists another way of classifying research and development activities. This is in terms of scientific disciplines. In other words in terms of the scientific speciality involved in the research project. Unfortunately, however, this method of classification is much more complicated than is apparent at first glance. Quite apart from the problem of selecting an appropriate category into which to classify a given scientific activity, there is the whole question of selecting the appropriate system of classification.

In the case of the South African survey the system of classification employed is one which was drawn up by the Office of the Scientific Adviser to the Prime Minister, and which has been published under the title: National subject list classification of disciplines of study in pure and applied natural sciences.[1)]

Although this system was drawn up before the survey of research and development was planned and consequently was unsuitable in many respects as a basis for classifying research and development data, it was preferred above the system suggested by the Frascati Manual because it met more precisely the needs of the Scientific Advisory Council in South Africa. This system also constitutes the basis for

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1) DEPARTMENT OF PLANNING: National subject list classification of disciplines of study in pure and applied natural sciences, Pretoria, 1967 (Department of Planning).

the Register of Scientific Manpower in South Africa which is being compiled on behalf of the Office of the Scientific Adviser. Consequently the data on research and development expenditure should be reconcilable with the data contained in the Register of Scientific Manpower.

The system suggested by the Frascati Manual on the other hand is based on a modification undertaken by the Organisation for Economic Co-operation and Development on the basis of a system drawn up by the United Nations Educational Social and Cultural Organization. It is interesting to note that the United Nations system was also intended as a classification for manpower statistics rather than research and development statistics and that the revision by the Organisation for Economic Co-operation and Development represented an attempt to obtain a more suitable classification for the purpose of classifying research and development statistics. According to the Frascati Manual ... "there appear to be still ambiguities in the UNESCO/O.E.C.D. classification, and it is to be hoped that the work now in progress in this field will soon result in an improved standard rubric for this purpose, and more detailed guidance for respondents. Owing to new developments in science itself, this type of classification will require regular reconsideration and revision, and this type of work should be a normal part of O.E.C.D. activities in this field".[1)]

It is obvious therefore that much remains to be done in this connection and until such time as an appropriate international

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1) ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT: Proposed standard practice for surveys of research and development, op. cit. p. 25.

classification is developed, it may be expected that the South African survey will be conducted in terms of a locally adapted classification.

It should be pointed out, however, that the South African method of classification is unsuitable in many respects. Probably the most important of these is the problem of classifying the activity development in terms of its constituent scientific disciplines. In practice this proved so difficult that it was eventually decided not to attempt it.

(iii) Fields of application of research

Another way of classifying research and development activities is in terms of their fields of application. This method of classification can be employed for all research and development activities which are undertaken with a particular field of application in mind. It is therefore a suitable method of classification for development and applied research but does not make allowance for basic research. (One could of course define basic research as a field of application in itself, in which case the classification of research in terms of fields of application would take place for the whole body of research and development proper).

To derive a suitable method of classification of fields of application of research it is convenient to begin with three social desiderata. These are:

(aa) Longevity and health.

(bb) Material wellbeing.

(cc) Freedom from foreign interference.

(aa) Longevity and health

Research and development can contribute to longevity and health by contributing towards:

- improved medical practices,
- realistic and efficient health regulations,
- procedures for ensuring the continued livability of the environment.

(bb) Material wellbeing

The contribution to material wellbeing by research and development can occur through:

- increased productivity within private enterprises and public corporations,
- increasing the productivity of factors of production across the board without limiting the influence to a particular sector,
- maintaining an environment in which economic activity can flourish without danger of congestion and excessive pollution.

(cc) Freedom from foreign interference is, of course, achieved through defence research.

While the three basic desiderata mentioned above in themselves give a fairly good outline of fields of application of research endeavour, it is desirable to break the first part of category (bb) down even further, and to specify the various sectors of the economy as far as possible. Consequently the practice has arisen to sub-classify the field of application, "material wellbeing", into two major categories, namely:

First, that relating to particular sectors of the economy: This covers the research work undertaken by or on behalf of, particular private enterprises and public corporations, as well as other economic organizations concerned with supplying infra-structural services, and which may be identified with a particular sector of the economy; and

second, that relating to the economy as a whole, which includes research done on the environment as well as research done on factors of production common to all branches of industry

To summarize then, four fields of application are identified.

(aa) industrial undertakings or other forms of (business or public) enterprise - in which case the field of application is the particular economic sector in which the industry or enterprise operates,

(bb) control or improvement of the environment, and improvement in common factors of production, contributing to the economy as a whole,

(cc) medical practice or procedure, health regulations, or environmental livability, contributing towards the health of the community,

(dd) the national defence establishment.

Problems do, of course, arise in selecting a suitable sector into which a particular research project or research activity should be classified. In this connection three criteria are usually employed.

Firstly, if the research worker himself has identified a field of application and is working towards it, the field of application thus identified is the appropriate one. This rule also applies to research workers working within a research organization and where the object of each research project is pre-determined.

Secondly, if two or more sectors stand to benefit from the project, the degree to which the results of the research are applied in each sector may be said to be proportional to the gains generated in each sector. In the case of research aimed at economic objectives these gains are equal to the additions to the national income generated in each sector (or, alternatively, proportional to the loss of national income averted in each sector). This is, of course, a highly theoretical distinction which cannot be perfectly implemented in practice and which can only serve as a guide when allocations are estimated. When the field of application is not a particular economic sector this distinction becomes even more difficult.

Thirdly, if the research is undertaken on contract on behalf of an outside organization, the field of application is that with which the sponsor is identified.

C. Statistics of expenditure on research and development

(a) Overall features

(i) Total expenditure

Data on the total expenditure on research and development undertaken in South Africa during the financial year 1966/67 and the academic year 1966[1] is given in Table XI. From the table it can be seen that this expenditure amounted to nearly R37 million, excluding expenditure on land and buildings. If the latter is taken into account as well, the figure amounts to nearly R40 million.

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1) For the sake of brevity, the expression "financial year 66/67 and the academic year 1966" will henceforth be written as "financial year 1966/67*"

TABLE XI

EXPENDITURE ON RESEARCH AND DEVELOPMENT IN THE NATURAL SCIENCES IN SOUTH AFRICA DURING THE FINANCIAL YEAR 1966/67 AND THE ACADEMIC YEAR 1966

(Figures represent R values)

FINANCIERS / PERFORMERS OF RESEARCH	GOVERNMENT SECTOR: Government Departments	GOVERNMENT SECTOR: Provincial Administrations	GOVERNMENT SECTOR: STATUTORY BODIES: Council for Scientific and Industrial Research	GOVERNMENT SECTOR: STATUTORY BODIES: Atomic Energy Board	GOVERNMENT SECTOR: STATUTORY BODIES: National Institute for Metallurgy	GOVERNMENT SECTOR: SUB-TOTAL	HIGHER EDUCATION SECTOR: Universities and University Colleges	BUSINESS ENTERPRISE SECTOR: Public Corporations	BUSINESS ENTERPRISE SECTOR: Business Enterprises	BUSINESS ENTERPRISE SECTOR: Industrial Research Institutes	BUSINESS ENTERPRISE SECTOR: SUB-TOTAL	PRIVATE PERSONS & NON-PROFIT INSTITUTIONS: Non-Profit Institutions	TOTAL	Percentage of Total
GOVERNMENT SECTOR:														
Government Departments	12,417,538	-	5,683,357	2,277,008	654,934	21,032,837	698,464	-	254,795	-	254,795	202,137	22,188,233	60.2
Provincial Administrations	-	223,347	126,922	-	-	350,269	31,620	-	-	17,690	17,690	50,497	450,076	1.2
Local Authorities	-	-	46,675	-	-	46,675	1,300	-	-	-	-	14,970	62,945	0.2
Statutory Bodies: Council for Scientific and Industrial Research	-	-	-	-	-	-	589,613	-	1,400	196,310	197,710	125,321	912,644	2.5
Atomic Energy Board	-	-	-	-	105,000	105,000	91,817	-	-	-	-	3,810	200,627	0.5
National Institute for Metallurgy	-	-	-	-	-	-	5,970	-	-	-	-	-	5,970	..
Sub-Total	12,417,538	223,347	5,856,954	2,277,008	759,934	21,534,781	1,418,784	-	256,195	214,000	470,195	396,735	23,820,495	64.6
HIGHER EDUCATION SECTOR:														
Universities & University Colleges	-	-	-	-	-	-	907,433	-	-	-	-	7,190	914,623	2.5
BUSINESS ENTERPRISE SECTOR:														
Public Corporations	-	-	4,670	454,936	-	459,606	150	1,906,274	-	-	1,906,274	1,644	2,367,674	6.4
Business Enterprises	2,038	-	276,988	786,902	1,237	1,067,165	215,254	-	7,282,633	125,119	7,407,752	54,906	8,745,077	23.8
Industrial Research Institutes	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Sub-Total	2,038	-	281,658	1,241,838	1,237	1,526,771	215,404	1,906,274	7,282,633	125,119	9,314,026	56,550	11,112,751	30.2
PRIVATE PERSONS & NON-PROFIT INSTITUTIONS														
Non-Profit Institutions	-	-	59,223	-	-	59,223	133,150	-	-	-	-	314,025	506,398	1.4
FOREIGN ORGANIZATIONS	-	-	20,600	-	-	20,600	175,501	-	-	-	-	291,041	487,142	1.3
TOTAL	12,419,576	223,347	6,218,435	3,518,846	761,171	23,141,375	2,850,272	1,906,274	7,538,828	339,119	9,784,221	1,065,541	36,841,409	100.0
Percentage of Total	33.7	0.6	16.9	9.5	2.1	62.8	7.7	5.2	20.5	0.9	26.6	2.9	100.0	
Basic Research	1,376,251 (11.1)	3,830 (1.7)	1,388,500 (22.3)	796,600 (22.7)	- (0.0)	3,565,181 (15.4)	1,991,871 (69.9)	509,271 (26.7)	184,030 (2.4)	80,114 (23.6)	773,415 (7.9)	539,812 (50.7)	6,870,299 (18.7)	
Applied Research	9,808,219 (79.0)	191,945 (85.9)	3,924,480 (63.1)	2,302,403 (65.4)	529,291 (69.5)	16,756,338 (72.4)	798,480 (28.0)	1,184,443 (62.1)	2,834,011 (37.6)	195,755 (57.7)	4,214,209 (43.1)	525,729 (49.3)	22,294,756 (60.5)	
Development	1,235,106 (9.9)	27,572 (12.4)	905,455 (14.6)	419,843 (11.9)	231,880 (30.5)	2,819,856 (12.2)	59,921 (2.1)	212,560 (11.2)	4,520,787 (60.0)	63,250 (18.7)	4,796,597 (49.0)	- (0.0)	7,676,374 (20.8)	

Percentages in lower part of table add to 100% when summed vertically.

It is interesting to compare this figure with an estimate of scientific expenditure budgeted by the Government for 1944, and of funds spent by industry during that year.[1)] The figure given is £718,000 and is considered a wide estimate. If this figure is assumed correct the growth rate of research and development expenditure in South Africa over the period 1944 to 1966 is between 15 and 16 per cent per annum.

This figure may be compared with approximately 14 per cent annual rate of growth for the USA over the thirty year period 1931 to 1961 and approximately 15 per cent per annum over the decade 1951 to 1961.[2)] Over the decade 1953 to 1963 the growth rate amounted to 13 per cent per annum.[3)]

However, in making this comparison it must be borne in mind that no allowance has been made for differential rates of inflation, and that the South African growth rate is probably a little unrealistic in view of the fact that it includes the initial acceleration stage while the American growth rate refers to the stage of "steady growth".

(ii) Research effort of various sectors

Of the total of nearly R37 million, the government sector undertook research to the value of R23 million (62.8 per cent of the total) while the business enterprise sector performed

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1) SOUTH AFRICAN COUNCIL FOR SCIENTIFIC AND INDUSTRIAL RESEARCH: <u>Objects and policies of the CSIR (an initial statement)</u>, Pretoria, December 1945 (The Mint) p. 6.

2) Calculations based on data in : HAMBERG, Daniel: <u>R & D : Essays on the economics of research and development</u>, New York, 1966 (Random House) p. 6.

3) UNITED STATES OF AMERICA, NATIONAL SCIENCE FOUNDATION: <u>Reviews of data on science resources</u>, vol. 1, no. 4, May 1965, p. 5.

research to the value of R9.8 million (or 26.6 per cent of the total). Institutions for higher education spent R2.8 million (amounting to 7.7 per cent of the total) while the private sector non-profit institutions, spent just over R1 million (or 2.9 per cent of the total). The ratio of research undertaken within the government sector to research undertaken within the business enterprise sector is approximately 5:2.

Within the government sector itself, a distinction is drawn between government departments and provincial administrations on the one hand, and the three statutory councils on the other. It will be noted that the sum of the expenditure by government departments and provincial administrations exceeded the sum of the expenditure of the three statutory bodies by approximately R2½ million. Government departments and provincial administrations contributed 34.3 percentage points of the 62.8 per cent spent by the government sector, while the three statutory councils together contributed the remaining 28.5 percentage points.

(iii) The relationship between financiers and performers of research

When the funds spent on research by each sector are expressed as a percentage of the monies provided by that sector, the following ratios are obtained: government sector, 97.2 per cent; business enterprise sector, 88.1 per cent; higher education sector, 308.0 per cent; non-profit institutions, 223.1 per cent.

The interesting feature to be noted in these ratios is the virtual parity between funds allocated to research and funds spent on research in the case of both the business enterprise and the government sectors. Very few inter-sectoral transactions for the purposes of research take place.

The high percentages observed in the case of the higher education sector and the non-profit institutions sector are to be expected, for these sectors do not generate own funds to any marked degree. Furthermore, the absolute amounts involved are fairly small so that even small differences in an absolute sense seem large when expressed in percentage terms.

(iv) Expenditure broken down into basic research, applied research and development

For the country as a whole, the breakdown between basic research, applied research and development amounted to 18.7 per cent, 60.5 per cent, and 20.8 per cent respectively during the financial year 1966/67*. However, when the four sectors are taken individually this breakdown differs rather significantly from that for the aggregate.

In the case of the government sector, the breakdown between basic research, applied research and development amounts to 15.4 per cent, 72.4 per cent and 12.2 per cent respectively, while in the case of the higher education sector, the corresponding values are 69.9 per cent, 28.0 per cent, and 2.1 per cent. This is very much in keeping with what one would expect from the nature of research and development undertaken by these organizations. The large share of basic research in the case of the universities is in keeping with the essentially educational responsibility of these institutions, while the predominance of applied research in the case of the government sector, reflects the interest of this sector in social (extra-scientific) goals.

For the business enterprise sector the breakdown between basic research, applied research and development amounted to 7.9 per cent, 43.1 per cent and 49.0 per cent, which emphasizes the relative importance of development as an essential step in bringing scientific discoveries to commercial fruition.

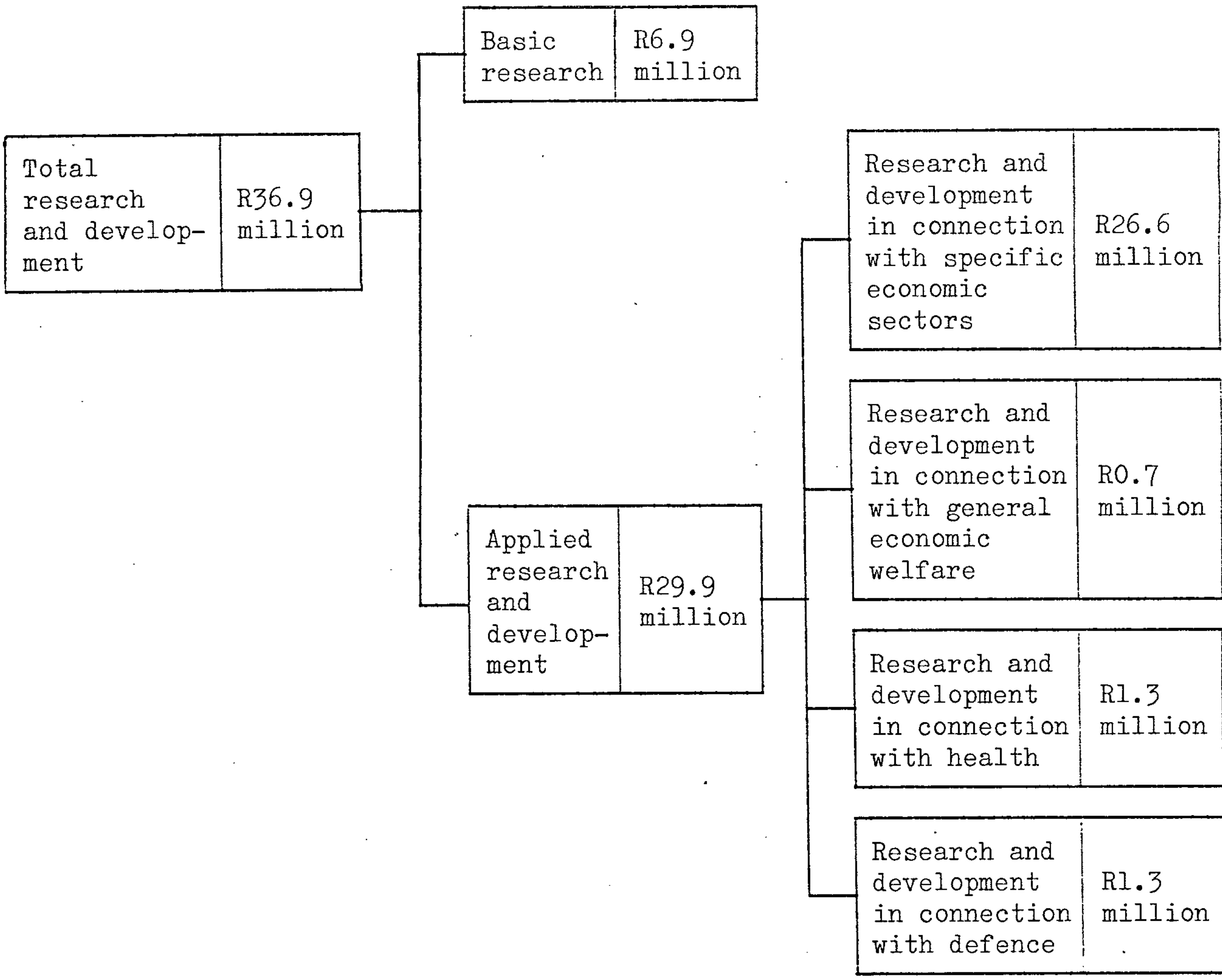
The profile for non-profit institutions, namely: 50.7 per cent basic research, and 49.3 per cent applied research, falls half way between that of universities and the government sector. Again this is in line with what could be expected in view of the fact that most of the non-profit institutions in South Africa are either museums or observatories, although medical research is also undertaken by an institution falling within this category.

(b) Expenditure on research and development broken down into fields of application

From the above general features, we may now proceed to a more explicit breakdown of expenditure on research and development in terms of fields of application. Diagram I gives the first broad perspective.

For a further breakdown of the category expenditure on research in connection with specific economic sectors the reader is referred to Table XII in which details are given of applied research and development expenditure broken down into the various sectors of the economy as well as into the three categories; research in connection with general economic welfare, research in connection with health and research in connection with defence.

Diagram I. <u>BREAKDOWN OF TOTAL EXPENDITURE ON RESEARCH AND DEVELOPMENT INTO VARIOUS BROAD CATEGORIES</u>



It is interesting to note that of the total expenditure on applied research and development, approximately 38 per cent is absorbed by the sector <u>agriculture, forestry and fisheries</u>, on whose behalf the largest research allocation is spent. The second largest allocation namely, just over 9 per cent relates to the sector <u>gold mining</u>, while the third largest allocation is in respect of the sector <u>electricity, gas and water</u>. Two sectors have expenditure shares equal to approximately 4 per cent of the total of applied research and development. These are <u>other mining and quarrying</u>, and <u>basic industrial chemicals</u>; while the shares of Health, and Defence are

TABLE XII

EXPENDITURE ON APPLIED RESEARCH AND DEVELOPMENT BROKEN DOWN INTO THE FIELDS OF APPLICATION

(Figures represent R. values)

SECTOR OF THE ECONOMY	GOVERNMENT SECTOR						HIGHER EDUCATION SECTOR	BUSINESS ENTERPRISE SECTOR				NON-PROFIT SECTOR		
			STATUTORY BODIES											
	Government Depart-ments	Provincial Administ-rations	Council for Scientific and Industrial Research	Atomic Energy Board	National Institute for Metal-lurgy	SUB-TOTAL	Universi-ties and University Colleges	Public Corpora-tions	Industrial Research Institutes	Business Enter-prises	SUB-TOTAL	Observator-ries, Mu-seums etc.	TOTAL	PERCENTAGE OF TOTAL
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1. Agriculture, forestry and fisheries	9,953,055	207,517	104,519	-	-	10,265,091	358,958	5,957	83,833	630,613	720,403	39,944	11,384,395	37.98
2. Gold Mining (including uranium)	9,227	-	181,440	347,127	272,232	810,026	29,074	-	-	2,010,720	2,010,720	-	2,849,820	9.51
3. Coal Mining	14,027	-	4,508	-	-	18,535	6,204	-	-	411,132	411,132	-	435,871	1.45
4. Other mining and quarrying	33,826	-	33,983	36,384	450,880	555,073	7,253	249,300	1,500	550,294	801,094	-	1,363,420	4.55
5. Processed foodstuffs (excluding beverages)	264,047	-	149,662	-	-	413,709	27,260	-	50,783	30,980	81,763	-	522,732	1.74
6. Beverages and tobacco	147,702	-	85,867	-	-	233,569	690	-	-	136,200	136,200	-	370,459	1.24
7. Textiles	-	-	290,643	-	-	290,643	390	11,500	-	1,150	12,650	-	303,683	1.01
8. Knitting mills	-	-	1,250	-	-	1,250	-	-	-	-	-	-	1,250	..
9. Clothing	-	-	1,250	-	-	1,250	-	-	-	-	-	-	1,250	..
10. Footwear	-	-	1,250	-	-	1,250	-	-	41,500	-	41,500	-	42,750	.14
11. Wood and wood products (excluding furniture)	79,627	-	97,150	-	-	176,777	-	-	-	-	-	-	176,777	.59
12. Furniture and fixtures	-	-	1,874	-	-	1,874	-	-	-	-	-	-	1,874	.01
13. Pulp and paper products	-	-	70,242	-	-	70,242	-	-	-	99,100	99,100	-	169,342	.57
14. Printing, publishing and allied industries	220	-	1,250	-	-	1,470	14,763	-	-	1,400	1,400	-	17,633	.06
15. Leather and leather products (excluding footwear)	-	-	6,635	-	-	6,635	-	-	43,500	-	43,500	-	50,135	.17
16. Rubber products	-	-	1,250	-	-	1,250	361	-	-	-	-	-	1,611	.01

17/...

SECTOR OF THE ECONOMY	GOVERNMENT SECTOR						HIGHER EDUCATION SECTOR	BUSINESS ENTERPRISE SECTOR				NON-PROFIT SECTOR	TOTAL	PERCENTAGE OF TOTAL
			STATUTORY BODIES											
	Government Depart- ments	Provincial Administ- rations	Council for Scientific and Industrial Research	Atomic Energy Board	National Institute for Metal- lurgy	SUB- TOTAL	Universi- ties and University Colleges	Public Corpora- tions	Industrial Research Institutes	Business Enter- prises	SUB- TOTAL	Observator- ries, Mu- seums etc		
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
17. Basic industrial chemicals	-	-	80,949	-	-	80,949	1,817	-	-	1,139,574	1,139,574	-	1,222,340	4.08
18. Miscellaneous chemical products	-	-	125,321	-	-	125,321	1,607	-	31,121	257,014	288,135	-	415,063	1.38
19. Products of petroleum and coal	1,900	-	20,410	-	-	22,310	-	427,646	-	-	427,646	-	449,956	1.50
20. Non-metallic mineral products	-	-	22,724	-	38,059	60,783	3,252	-	-	815,086	815,086	-	879,121	2.93
21. Basic iron and steel industries	1,900	-	50,885	-	-	52,785	4,908	702,600	-	162,751	865,351	-	923,044	3.08
22. Non-ferrous metal basic industries	1,000	-	7,600	124,675	-	133,275	1,699	-	-	13,432	13,432	-	148,406	.50
23. Metal products (excluding machinery and transport equipment)	-	-	10,727	-	-	10,727	3,358	-	-	107,848	107,848	-	121,933	.41
24. Machinery (excluding electrical machinery)	18,691	-	92,350	-	-	111,041	-	-	-	12,021	12,021	-	123,062	.41
25. Electrical machinery and equipment	38,023	-	167,479	-	-	205,502	6,605	-	-	411,200	411,200	-	623,307	2.08
26. Transport equipment (excluding motor vehicles)	208,750	-	33,350	-	-	242,100	475	-	-	11,768	11,768	-	254,343	.85
27. Motor Vehicles	-	-	1,250	-	-	1,250	361	-	-	56,550	56,550	-	58,161	.19
28. Miscellaneous manufacturing industries	-	-	30,200	28,593	-	58,793	7,957	-	-	128,106	128,106	-	194,856	.65
29. Construction	12,200	-	728,368	-	-	740,568	10,698	-	-	236,530	236,530	-	987,796	3.29
30. Electricity, gas and water	6,257	-	211,168	1,949,928	-	2,167,353	2,299	-	-	80,407	80,407	-	2,250,059	7.51

31/...

SECTOR OF THE ECONOMY	GOVERNMENT SECTOR						HIGHER EDUCATION SECTOR	BUSINESS ENTERPRISE SECTOR				NON-PROFIT SECTOR	TOTAL	PERCENTAGE OF TOTAL
			STATUTORY BODIES											
	Government Departments	Provincial Administrations	Council for Scientific and Industrial Research	Atomic Energy Board	National Institute for Metallurgy	SUB-TOTAL	Universities and University Colleges	Public Corporations	Industrial Research Institutes	Business Enterprises	SUB-TOTAL	Observatories, Museums etc.		
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
31. Trade (wholesale and retail)	45,991	-	1,250	-	-	47,241	-	-	-	-	-	-	47,241	.16
32. Motor trade and repairs	-	-	2,094	-	-	2,094	-	-	-	-	-	-	2,094	.01
33. Transport and communication	79,086	-	79,750	-	-	158,836	-	-	-	18,656	18,656	-	177,492	.59
34. Miscellaneous services	-	-	1,250	-	-	1,250	3,524	-	-	-	-	-	4,774	.02
SUB-TOTAL	10,915,529	207,517	2,699,898	2,486,707	761,171	17,070,821	493,513	1,397,003	252,237	7,322,532	8,971,772	39,944	26,576,050	88.67
General Economic Welfare	108,297	8,000	451,574	-	-	567,871	79,693	-	6,768	28,681	35,449	76,000	759,013	2.53
Health	19,500	4,000	366,261	235,539	-	625,300	275,787	-	-	-	-	409,785	1,310,872	4.38
Defence	-	-	1,312,202	-	-	1,312,202	9,408	-	-	3,585	3,585	-	1,325,195	4.42
TOTAL EXPENDITURE	11,043,325	219,517	4,829,935	2,722,246	761,171	19,576,194	858,401	1,397,003	259,005	7,354,798	9,010,806	525,729	29,971,130	100.00

also of this order of magnitude. Very little is allocated for the sectors knitting mills; clothing; furniture and fixtures; rubber products; and motor trade and repairs.

While this breakdown does provide an interesting first view of the allocation of research and development effort to various fields of application, it is misleading in that it does not relate this effort to the magnitude of that which is being served. In the case of the various sectors of the economy, the deficiency is easily remedied by expressing research and development expenditure as a percentage of the value added by each sector. This is undertaken in Chapter 4, Sub-section 4.3 A (a) and we will not investigate it any further here.

(c) Expenditure on research and development broken down into scientific disciplines

As was pointed out in Sub-section 3.2 B (c)(ii) it is not possible to allocate expenditure on development in terms of scientific disciplines; only expenditure on basic and applied research may be further apportioned in this way. The details about the breakdown of expenditure on basic research and applied research is given in Table XIII.

From Table XIII, it will be seen that the largest expenditures in the field of basic and applied research relates to the group of sciences associated with biology, agriculture and forestry. This includes: animal science, botany, forestry, genetics, etc. This group absorbs 31.9 per cent of the expenditure specified. This group is followed by engineering absorbing 21.7 per cent of the expenditure specified, while the third largest group is chemistry with a figure of 15.5 per cent. The categories medical sciences,

TABLE XIII

EXPENDITURE ON BASIC AND APPLIED RESEARCH IN SOUTH AFRICA DURING THE FINANCIAL YEAR 1966/67 AND THE ACADEMIC YEAR 1966, BROKEN DOWN IN TERMS OF SCIENTIFIC DISCIPLINES

SCIENTIFIC DISCIPLINE	GOVERNMENT SECTOR						HIGHER EDUCATION SECTOR	BUSINESS ENTERPRISE SECTOR				NON-PROFIT ORGANIZATIONS	TOTAL	PERCENTAGE OF TOTAL
			STATUTORY BODIES											
	Government Departments	Provincial Administrations	Council for Scientific and Industrial Research	Atomic Energy Board	National Institute for Metallurgy	SUB-TOTAL	Universities and University Colleges	Public Corporations	Industrial Research Institutes	Business Enterprises	SUB-TOTAL	Observatories, Museums etc.		
1. ASTRONOMY; LAND SURVEYING	6,165	-	31,645	-	-	37,810	13,157	-	-	-	-	292,964	343,931	1.2
1.1 Astronomy	-	-	7,247	-	-	7,247	6,202	-	-	-	-	292,964	306,413	1.1
1.2 Cadastral Land Surveying	6,165	-	-	-	-	6,165	3,477	-	-	-	-	-	9,642	..
1.3 Geodesy	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1.4 Mine Surveying	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1.5 Photogrammetry	-	-	-	-	-	-	3,478	-	-	-	-	-	3,478	-
1.6 Regional Planning	-	-	24,398	-	-	24,398	-	-	-	-	-	-	24,398	0.1
1.7 Surveying	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1.8 Town Planning	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2. BIOLOGY; AGRICULTURE; FORESTRY	7,561,678	192,505	237,380	-	-	7,991,563	562,686	5,957	14,710	449,134	469,801	274,257	9,298,307	31.9
2.1 Agricultural Economics and information	287,065	-	1,595	-	-	288,660	25,481	-	-	48,222	48,222	-	362,363	1.2
2.2 Applied Animal Sciences	1,897,973	144,472	14,189	-	-	2,056,634	58,310	-	-	9,400	9,400	766	2,125,110	7.3
2.3 Botany	707,437	24,010	25,964	-	-	757,411	79,511	-	-	25,561	25,561	767	863,250	3.0
2.4 Forestry	227,142	-	-	-	-	227,142	57,389	-	-	64,565	64,565	-	349,096	1.2
2.5 Genetics	418,288	-	-	-	-	418,288	57,178	-	-	25,561	25,561	-	501,027	1.7
2.6 Microbiology and plant pathology	584,528	-	143,430	-	-	727,958	58,125	-	9,160	65,286	74,446	-	860,529	2.9
2.7 Plant Production	2,050,050	-	-	-	-	2,050,050	67,402	-	-	131,348	131,348	-	2,248,800	7.8
2.8 Soil Science	490,987	-	-	-	-	490,987	33,440	-	-	28,222	28,222	-	552,649	1.9
2.9 Zoological Sciences	898,208	24,023	52,202	-	-	974,433	125,850	5,957	5,550	50,969	62,476	272,724	1,435,483	4.9

The notation .. indicates that the value is less than 0.05%

SCIENTIFIC DISCIPLINE	GOVERNMENT SECTOR						HIGHER EDUCATION	BUSINESS ENTERPRISE SECTOR				NON-PROFIT ORGANIZATIONS	TOTAL	PERCENTAGE OF TOTAL
			STATUTORY BODIES											
	Government Departments	Provincial Administrations	Council for Scientific and Industrial Research	Atomic Energy Board	National Institute for Metallurgy	SUB-TOTAL	Universities and University Colleges	Public Corporations	Industrial Research Institutes	Business Enterprises	SUB-TOTAL	Observatories, Museums etc.		
3. CHEMISTRY	983,100	-	723,712	830,421	210,108	2,747,341	350,863	578,840	129,432	709,438	1,417,710	-	4,515,914	15.5
3.1 Analytical Chemistry	243,546	-	28,562	209,966	165,689	647,763	62,506	32,014	38,682	149,978	220,674	-	930,943	3.2
3.2 Biochemistry	606,629	-	158,178	146,422	-	911,229	119,076	-	8,980	1,825	10,805	-	1,041,110	3.6
3.3 Enzymatic and Micro-biological Chemistry	-	-	83,886	-	-	83,886	2,427	-	-	14,825	14,825	-	101,138	0.3
3.4 Inorganic Chemistry	5,961	-	200,225	31,285	-	237,471	28,167	45,373	1,900	99,754	147,027	-	412,665	1.4
3.5 Metallurgical and Geochemistry	-	-	14,573	60,738	44,419	119,730	11,079	150,700	-	144,667	295,367	-	426,176	1.5
3.6 Organic Chemistry	94,057	-	117,098	-	-	211,155	67,202	159,608	50,754	129,860	340,222	-	618,579	2.1
3.7 Pathological Chemistry	-	-	-	-	-	-	312	-	-	-	-	-	312	..
3.8 Physical Chemistry	-	-	101,051	382,010	-	483,061	60,088	191,145	29,116	105,148	325,409	-	868,558	3.0
3.9 Soil Chemistry	32,907	-	15,817	-	-	48,724	6	-	-	63,381	63,381	-	112,111	0.4
Not applicable elsewhere	-	-	4,322	-	-	4,322	-	-	-	-	-	-	4,322	..
4. EARTH SCIENCES	850,326	-	429,942	-	98,957	1,379,225	321,775	52,320	-	179,969	232,289	83,643	2,016,932	6.9
4.1 Agrometeorology	135,467	-	-	-	-	135,467	7,355	-	-	108,555	108,555	-	251,377	0.9
4.2 Architecture and Quantity Surveying	-	-	101,805	-	-	101,805	3,524	-	-	-	-	-	105,329	0.4
4.3 Geography	-	-	-	-	-	-	7,004	-	-	-	-	-	7,004	..
4.4 Geology	5,144	-	87,106	-	98,957	191,207	117,811	52,320	-	69,195	121,515	1,081	431,614	1.5
4.5 Geophysics	6,940	-	26,928	-	-	33,868	61,349	-	-	2,219	2,219	-	97,436	0.3
4.6 Oceanography	486,564	-	161,519	-	-	648,083	85,771	-	-	-	-	-	733,854	2.5
4.7 Meteorology	146,467	-	40,618	-	-	187,085	13,075	-	-	-	-	-	200,160	0.7
4.8 Palaeontology	5.144	-	11,966	-	-	17,110	25,886	-	-	-	-	54,010	97,006	0.3
*4.9 (Archaeology)	-	-	-	-	-	-	-	-	-	-	-	28,552	28,552	0.1
*4.10 (Hydrology)	64,600	-	-	-	-	64,600	-	-	-	-	-	-	64,600	0.2

The notation .. indicates that the value is less than 0.05%

* Not in the original classification

SCIENTIFIC DISCIPLINE	GOVERNMENT SECTOR						HIGHER EDUCATION	BUSINESS ENTERPRISE SECTOR				NON-PROFIT ORGANIZATIONS		
			STATUTORY BODIES											
	Government Departments	Provincial Administrations	Council for Scientific and Industrial Research	Atomic Energy Board	National Institute for Metallurgy	SUB-TOTAL	Universities and University Colleges	Public Corporations	Industrial Research Institutes	Business Enterprises	SUB-TOTAL	Observatories, Museums etc.	TOTAL	PERCENTAGE OF TOTAL
5. ENGINEERING	465,320	-	2,032,495	1,466,420	220,226	4,184,461	137,865	803,300	25,795	1,185,278	2,014,373	-	6,336,699	21.7
5.1 Agricultural Engineering	199,731	-	-	-	-	199,731	16,500	-	-	-	-	-	216,231	0.7
5.2 Chemical Engineering	-	-	137,304	57,756	162,471	357,531	10,243	219,800	21,860	87,977	329,637	-	697,411	2.4
5.3 Civil Engineering	141,619	-	719,176	-	-	860,795	15,062	-	-	62,900	62,900	-	938,757	3.2
5.4 Electrotechnical Engineering	75,408	-	224,530	272,095	-	572,033	30,216	172,800	-	128,805	301,605	-	903,854	3.1
5.5 Industrial Engineering	-	-	6,500	-	-	6,500	2,076	-	-	29,252	29,252	-	37,828	0.1
5.6 Mechanical Engineering	13,718	-	150,900	581,998	-	746,616	25,183	129,600	555	139,795	269,950	-	1,041,749	3.6
5.7 Metallurgical Engineering	9,900	-	16,800	554,571	57,755	639,026	25,104	100,700	-	158,089	258,789	-	922,919	3.2
5.8 Mining Engineering	24,944	-	83,600	-	-	108,544	12,574	180,400	-	565,214	745,614	-	866,732	3.0
5.9 Miscellaneous Engineering	-	-	693,685	-	-	693,685	907	-	3,380	13,246	16,626	-	711,218	2.4
6. MATHEMATICS: STATISTICS	205,776	-	249,952	-	-	455,728	63,042	-	5,500	29,555	35,055	4,892	558,717	1.9
6.1 Biometry	205,776	-	923	-	-	206,699	13,901	-	2,500	9,355	11,855	-	232,455	0.8
6.2 Mathematics	-	-	20,307	-	-	20,307	25,138	-	-	-	-	-	45,445	0.1
6.3 Mathematical Methods	-	-	7,397	-	-	7,397	9,752	-	-	-	-	-	17,149	0.1
6.4 Statistics	-	-	221,325	-	-	221,325	14,251	-	3,000	20,200	23,200	4,892	263,668	0.9
7. MEDICAL SCIENCES	882,597	3,270	216,048	28,484	-	1,130,399	828,591	-	-	117,800	117,800	409,785	2,486,575	8.5
7.1 Dental Survey	-	-	1,846	-	-	1,846	27,540	-	-	-	-	-	29,386	0.1
7.2 Human Medicine	12,380	-	156,532	28,484	-	197,396	760,803	-	-	78,160	78,160	409,785	1,446,144	4.9
7.3 Supplementary Health Services	42,300	-	57,670	-	-	99,970	12,763	-	-	2,165	2,165	-	114,898	0.4
7.4 Veterinary Science	827,917	3,270	-	-	-	831,187	27,485	-	-	37,475	37,475	-	896,147	3.1

The notation .. indicates that the value is less than 0.05%

SCIENTIFIC DISCIPLINE	GOVERNMENT SECTOR: Government Departments	GOVERNMENT SECTOR: Provincial Administrations	GOVERNMENT SECTOR: STATUTORY BODIES: Council for Scientific and Industrial Research	GOVERNMENT SECTOR: STATUTORY BODIES: Atomic Energy Board	GOVERNMENT SECTOR: STATUTORY BODIES: National Institute for Metallurgy	GOVERNMENT SECTOR: SUB-TOTAL	HIGHER EDUCATION: Universities and University Colleges	BUSINESS ENTERPRISE SECTOR: Public Corporations	BUSINESS ENTERPRISE SECTOR: Industrial Research Institutes	BUSINESS ENTERPRISE SECTOR: Business Enterprises	BUSINESS ENTERPRISE SECTOR: SUB-TOTAL	NON-PROFIT ORGANIZATIONS: Observatories, Museums etc.	TOTAL	PERCENTAGE OF TOTAL
8. PHYSICS AND APPLIED MATHEMATICS	63,819	-	687,353	773,678	-	1,524,850	460,661	163,097	22,950	204,196	390,243	-	2,375,754	8.2
8.1 Acoustics	-	-	64,995	-	-	64,995	2,348	-	-	5,000	5,000	-	72,343	0.3
8.2 Applied Mathematics and Theoretical Physics	-	-	28,779	-	-	28,779	23,176	19,530	-	8,768	28,298	-	80,253	0.3
8.3 Applied Physics	63,819	-	120,880	244,683	-	429,382	30,462	-	22,950	160,380	183,330	-	643,174	2.2
8.4 Atom. and Molecular Physics	-	-	-	-	-	-	39,105	23,202	-	2,368	25,570	-	64,675	0.2
8.5 Electricity and Magnetics	-	-	47,491	-	-	47,491	11,450	-	-	4,736	4,736	-	63,677	0.2
8.6 Nuclear Physics	-	-	257,953	359,853	-	617,806	198,076	-	-	-	-	-	815,882	2.8
8.7 Optics	-	-	106,961	-	-	106,961	-	-	-	9,472	9,472	-	116,433	0.4
8.8 Solid-state Physics	-	-	46,369	169,142	-	215,511	156,044	120,365	-	13,472	133,837	-	505,392	1.8
8.9 Theory of heat	-	-	7,478	-	-	7,478	-	-	-	-	-	-	7,478	..
Not applicable elsewhere	-	-	6,447	-	-	6,447	-	-	-	-	-	-	6,447	..
9. TECHNOLOGY	165,689	-	470,983	-	-	636,672	51,711	90,200	77,482	142,671	310,353	-	998,736	3.4
9.1 Food Technology	127,764	-	90,653	-	-	218,417	16,221	-	20,540	9,546	30,086	-	264,724	0.9
9.2 Industrial Technology	220	-	109,111	-	-	109,331	35,490	90,200	56,942	133,125	280,267	-	425,088	1.5
9.3 Textile Technology	-	-	256,293	-	-	256,293	-	-	-	-	-	-	256,293	0.9
9.4 Wine Technology	37,705	-	-	-	-	37,705	-	-	-	-	-	-	37,705	0.1
Not applicable elsewhere	-	-	14,926	-	-	14,926	-	-	-	-	-	-	14,926	..
10. PSYCHOLOGY	-	-	233,470	-	-	233,470	-	-	-	-	-	-	233,470	0.8
TOTAL:	11,184,470	195,775	5,312,980	3,099,003	529,291	20,321,519	2,790,351	1,693,714	275,869	3,018,041	4,987,624	1,065,541	29,165,035	100

The notation .. indicates that the value is less than 0.05%

and physics and applied mathematics both absorb more than 8 per cent while the remaining four fields specified together were responsible for just over 13 per cent.

The relative importance of biology, agriculture and forestry can be explained by the predominance of agricultural research in South Africa, while the significance of engineering is derived from the activities of the Atomic Energy Board in the field of mechanical and metallurgical engineering, as well as the rôle of mining engineering in the business enterprise sector.

Medical sciences are inflated by the inclusion of veterinary science, which accounts for well over one third of the expenditure in that field, while in the grouping chemistry, biochemistry features as a consequence of its association with agricultural research.

In the grouping physics and applied mathematics, attention may be drawn to nuclear physics which accounts for approximately one third of the expenditure in that group.

(d) Summary of features

From the data presented above six features emerge which can be said to typify the research and development scene in the Republic.

First, the overwhelmingly important rôle played by the government sector in both financing and performing research - approximately two thirds of the total.

Second, the relatively small participation by universities in the overall research and development effort - approximately 8 per cent of the total effort.

Third, the somewhat restricted part played by the business enterprise sector (25 per cent of the total) in the overall research and development effort coupled with the fact that a significant part of this research (one fifth of the business enterprise sector) is performed in the laboratories of government owned corporations.

Fourth, the relatively limited resources devoted to development work (20 per cent of the total) while it is known that this is the most costly phase of the research and development spectrum.

Fifth, the large commitment of applied research and development funds to the problems of agriculture (nearly 40 per cent of the total) compared with the relatively more limited commitment to industry (nearly 30 per cent of the total).

Sixth, the concentration of basic research and applied research in scientific disciplines which are known for their eventual relevance to the problems of agriculture. (This feature may, of course, be pre-supposed by the fifth feature mentioned above.)

3.3 South African research and development expenditure compared with overseas countries

A. Aggregate research ratios

The first aspect of expenditure on research and development in South Africa which may be compared with overseas countries is the total expenditure on research and development expressed as a percentage of aggregate product. The measure of aggregate product chosen is gross national product at market prices. This is perhaps not the most suitable choice, as distortions occur from country to country depending on the magnitude of indirect taxation and subsidies. A more preferable measure would have been gross national product at factor cost. However, the ratio incorporating gross national product at market prices is one of the few ratios generally available and for that reason it was used.

The ratios calculated for a number of countries, are shown in Table XIV. It will be noted that the countries specified in Table XIV are classified into four classes. The first class consists of one country, namely the United States; the second class of four large industrialized countries; the third class of a number of smaller industrialized countries, and the fifth class of a number of semi-developed countries, among which South Africa. The general classification is based on one employed by the Organisation for Economic Co-operation and Development[1)] while the placing of South Africa in the fifth class has been motivated by South Africa's level of gross national product per capita, compared to that of the other countries.[2)]

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1) ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT: The overall level and structure of R & D efforts in OECD member countries, Paris, 1967 (OECD).

2) HARBISON, Frederick, and MYERS, Charles, A.: Education, manpower and economic growth: Strategies of human resourced development, New York, Toronto and London, 1964 (McGraw-Hill Book Company) p. 42.

TABLE XIV

INTERNATIONAL COMPARISON OF EXPENDITURE ON RESEARCH AND DEVELOPMENT AS A PERCENTAGE OF GROSS NATIONAL PRODUCT AT MARKET PRICES[1)]

Country	Year	Expenditure on research and development as a percentage of gross national product
United States	1963/64	3.4
United Kingdom	1964/65	2.3
France	1963	1.6
Germany	1964	1.4
Japan	1963	1.4
Italy	1963	0.6
Netherlands	1964	1.9
Sweden	1964	1.5
Canada	1963	1.1
Belgium	1963	1.0
Norway	1963	0.7
Austria	1963	0.3
South Africa	1966	0.5
Ireland	1963	0.5
Turkey	1964	0.4
Greece	1964	0.2
Portugal	1964	0.2
Spain	1964	0.2

1) ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT: The overall level and structure of R and D efforts in OECD member countries, op. cit., p. 21.

From the table it will be seen that South Africa devotes approximately 0.5 per cent of gross national product to research and development. This is significantly less than the United States and the United Kingdom with ratios of 3.4 and 2.3 per cent respectively, as well as for France, Germany, Japan, Netherlands and Sweden whose ratios ranged from 1.5 per cent to just under 2 per cent. The South African ratio is, however, equal to the ratio for Ireland, and higher than the ratios for Austria, Turkey, Greece, Portugal or Spain.

Also, it may be mentioned, that the aggregate research ratio for Australia amounted to 0.6 per cent in 1960.[1)]

B. Research and development expenditure broken down into national objectives

A second basis for comparing the pattern of expenditure on research and development in South Africa with that of overseas countries is in terms of the national objectives of research and development. Data could be readily obtained for a three-fold distinction between:

(i) Defence, space and atomic research and development.

(ii) Economically motivated research and development.

(iii) Welfare and miscellaneous research and development.

In the case of South Africa the latter category consists of medical research as well as all basic research.

The breakdown of expenditure on research and development into the categories specified is shown in Table XV. It will be noted that the same grouping of countries is adhered to as in Table XIV and that within each group the countries are arranged in order of each country's

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1) DEDIJER, Stevan: "Underdeveloped science for underdeveloped countries". Minerva, vol. II, no. 1, Autumn 1963, p. 62.

TABLE XV   INTERNATIONAL COMPARISON OF NATIONAL RESEARCH AND DEVELOPMENT OBJECTIVES AS A PERCENTAGE OF GROSS NATIONAL EXPENDITURE ON RESEARCH AND DEVELOPMENT[1]

Country	Year	Defence, space and atomic research and development	Economically motivated research and development	Welfare and miscellaneous research and development	Total
		%	%	%	%
United States	1963/64	62	28	10	100
France	1963/64	45	41	14	100
United Kingdom	1963/64	40	51	9	100
Italy	1963/64	21	63	16	100
Germany	1963/64	17	62	21	100
Japan	1963/64	..	73	27	100
Sweden	1963/64	34	50	16	100
Canada	1963/64	26	51	23	100
Norway	1963/64	14	56	30	100
Austria	1963/64	12	62	26	100
Netherlands	1963/64	5	70	25	100
Belgium	1963/64	4	82	14	100
Greece	1963/64	29	61	10	100
Spain	1963/64	17	64	19	100
South Africa[1]	1966	7	72	21	100
Portugal	1963/64	5	72	23	100
Ireland	1963/64		89	11	100

1) Ibid., p. 58.

2) Gross domestic expenditure on research and development.

percentage of total research and development expenditure devoted to defence, space and atomic research and development.

From Table XV it may be seen that South Africa is one of the countries with the lowest expenditure on research and development for defence, space and atomic purposes and the highest expenditure on economically motivated research and development. In the share of welfare and miscellaneous research and development as percentage of total expenditure on research and development, South Africa is in line with the general tendency.

C. Shares of basic research, applied research and development, in national totals

Table XVI contains a comparison between the breakdown of various countries' total research and development effort into basic research, applied research and development.

The arrangement of this table follows that of the previous two tables with countries being ranked in terms of the share of basic research. According to these data the share of resources devoted to basic research in South Africa falls within the range of the shares observed for the other countries in the table but in the case of both applied research and development the South African values are extremes. South Africa exhibited the highest share of national resources devoted to applied research, namely 60 per cent and the lowest share of national resources devoted to development, namely 20 per cent.

D. The rôle of government in the research and development scene

The last international comparison which will be undertaken concerns the rôle of government on the research and development scene. This can be expressed in two ways, namely, first, the government's share in financing total expenditure on research and development and second, the government's

TABLE XVI

INTERNATIONAL COMPARISON OF BASIC RESEARCH, APPLIED RESEARCH AND DEVELOPMENT AS A PERCENTAGE OF EXPENDITURE ON RESEARCH AND DEVELOPMENT[1)]

Country	Year	Basic research	Applied research	Development
United States	1964	12.4	22.1	65.5
Italy	1963	18.6	39.9	41.5
France	1963	17.3	33.9	48.8
United Kingdom	1964/65	12.5	26.1	61.4
Netherlands	1964	27.1	36.4	36.5
Austria	1963	22.6	31.9	45.5
Norway	1963	22.2	34.6	43.2
Belgium	1963	20.9	41.2	37.9
Spain	1964	25.4	48.1	26.5
Greece	1964	23.8	53.2	23.0
South Africa	1966/67	18.7	60.5	20.8
Ireland	1963	3.5	53.1	43.4

1) Ibid., p. 35

share in performing research and development.

Details of these ratios are given in Table XVII for a number of countries.

Again the countries are arranged in the same groups as in the previous tables and for each country a ratio is calculated of expenditure on research and development performed within the government sector to research and development financed by the government.

While South Africa by no means has the highest share of either government financing of research and development or government performance of research and development, its ratio of government's share of performance to financing is the highest for all the countries observed and amounted to 0.97 in 1966.

E. Concluding remarks

When comparing the South African research and development structure to that of a number of countries abroad, one is struck by the relatively low aggregate expenditure on research and development and at the same time by the large government participation and the large share of research effort devoted to applied research.

One may conclude that this is the typical composition of a country whose research effort is concentrated in the hands of government financed and controlled national laboratories who are greatly concerned with employing research to social advantage.

The relatively low share devoted to development may be ascribed to a generally low research intensity within South African industry, while the share devoted to basic research should be seen as a composite of two influences, namely, the relative meagre participation of universities in

TABLE XVII INTERNATIONAL COMPARISON OF THE ROLE OF THE GOVERNMENT IN RESEARCH AND DEVELOPMENT[1]

Country	Year	Percentage of expenditure on research and development financed from government sources	Percentage of expenditure on research and development performed within the government sector	Ratio of share in research and development performance to research and development financing
United States	1963/64	63.8	18.1	0.28
France	1963/64	63.3	36.2	0.57
United Kingdom	1963/64	56.6	23.0	0.41
Germany	1963/64	40.4	3.5	0.09
Italy	1963/64	33.1	22.0	0.66
Japan	1963/64	27.8	12.1	0.44
Canada	1963/64	54.5	43.1	0.79
Norway	1963/64	54.3	17.4	0.32
Sweden	1963/64	47.7	14.6	0.31
Austria	1963/64	40.3	9.0	0.22
Netherlands	1963/64	40.0	2.7	0.07
Belgium	1963/64	24.6	8.4	0.34
Greece	1963/64	82.1	74.1	0.90
Spain	1963/64	73.7	68.4	0.93
Portugal	1963/64	70.5	66.3	0.94
Ireland	1963/64	67.2	56.6	0.84
South Africa	1966	64.6	62.8	0.97

1) Ibid., p. 60.

the overall research and development effort in South Africa and, as a compensating factor, the phenomenon that the government laboratories and statutory councils normally devote approximately a fifth of their research and development effort to research of a basic nature.

4. IMPACT OF RESEARCH ON THE SOUTH AFRICAN ECONOMY

4.1 Introductory remarks

As emphasized in the extensive discussions in Sections 2.2 and 2.3 it is extremely difficult, if not impossible, to calculate for a given country the aggregate economic impact of science. The case of South Africa is no exception to this rule. Any impression that can be formed about the economic impact of science in South Africa at this stage, will be the result of careful probing, deduction and analysis, and will not be the consequence of empirical research and straightforward calculation. The task of the present Chapter therefore is to lay down certain guidelines in terms of which such an impression may be formed.

The analysis begins with a Section devoted to the various stages of economic growth which a country could be expected to pass through, and the typical research requirements of each stage. This provides a first perspective with regard to the size and composition of the research endeavour properly associated with the present stage of development.

The next Section deals with the magnitude of the South African research and development effort devoted to economic objectives. In this Section the research and development profile is superimposed upon the economic profile and the research intensity of the various economic sectors thus identified. Other relevant technological features of the South African economy are also described. This constitutes a second perspective about the economic contribution of science in the Republic.

Once this has been done, an estimate of technological change in South Africa is attempted as a first quantitative guideline in our analysis. The Chapter concludes with a discussion of various South African scientific achievements and of their economic importance.

4.2 Present stage of economic growth and scientific research requirements associated therewith

A. Pattern of economic development

We define economic growth as a steady increase in product per capita brought about by an increased ability of mankind to meet given human demands with less and less human effort. As part of the process of economic growth there occurs also a marked change in the sectoral composition of the labour force and in the sectoral origin of aggregate product.[1] These changes are sometimes seen as such an intrinsic feature of growth that it cannot be conceived without them. Accordingly the forces giving rise to change are interpreted as growth forces and their impact measured and held out as quantitative explanations of the phenomenon of economic growth.

From the point of view of the present dissertation, this method of approach in analysing economic growth is very convenient; as the said forces seem to follow one another in a given pattern and it is consequently possible to identify the current stage of development and prevailing economic tendencies in a given country.

According to Akamatsu the typical pattern of economic growth in developing countries involves three stages.[2] During the first (which presupposes that the aggregate product exceeds essential consumption requirements and that a surplus can be exported), imports grow rapidly as a source of supply, and in response to a consumer good demand vector exhibiting signs of increasing sophistication. The second stage is one in which the

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1) KUZNETS, Simon: Modern economic growth, its rate structure and spread, New Haven and London, 1966 (Yale University Press) pp. 86-112.

2) AKAMATSU, Kaname: "A theory of unbalanced growth in the world economy", Weltwirtschaftliches Archiv Band 86, Heft 2, 1961, pp. 205-207. This pattern of economic growth is described in the economic literature of Japan as a "wild-geese-flying pattern" (p. 205).

process of industrialization gains impetus from the opportunity to replace imported products with those of local manufacture. This phase is generally known as the phase of import substitution. From this phase emerges a third one in which exports increase rapidly and provide the growth thrust for further industrialization.

The evolution of production of capital and intermediate goods follows one stage behind the demand for consumer goods. In what is referred to above as the second stage, imports of capital goods increase in response to the development of an industrial base aimed at the import substitution of consumer goods. Whereas in the third stage (exports of consumer goods) the setting is provided for import substitution of capital goods.

This one-stage-lag in capital good manufacture implies that, logically, a fourth stage eventually emerges which is characterized by the exports of capital goods.

This model would seem to provide a reasonable approximation of the South African situation and is accepted for the purposes of the present dissertation.

B. <u>Typical research features of countries at various stages of economic development</u>

In the first stage of economic development typified above, it could be argued that very few scientific needs exist. The comparative advantages constituting the country's ability to export stem from either natural resource endowments or cheap labour. The process of innovation in these circumstances usually consists of adapting well known production processes (imported from abroad) to local circumstances without generating any "new" knowledge. Scope for technological advance in the agricultural sector could well exist, but it would seem fair to assume that this potential would, more often than not, be exploited by the importation of well-tried technologies from abroad rather than by the generation of new techniques within the country.

The second stage, in which products of local manufacture replace those of foreign origin, is already of a somewhat different nature. The general feature of this phase is that production plant is imported to establish local production facilities in a field for which there already exists a demand, as evidenced by the existence of imports. Production know-how is required, but it is usually readily obtained from abroad, and more often than not an agreement to this effect constitutes part of the purchase contract of capital equipment.

The research needs of the economy at this stage of economic development are fairly simple. Essentially they can be reduced to the problem of adapting foreign production processes to local circumstances. This adaptation process is essentially concerned with modifying foreign production processes, (which are usually designed for much larger markets and longer production runs than in the developing country) to meet local climatological and power requirements and operative skills.

As far as the organization of this type of research is concerned, it may be pointed out that because it deals with a problem common to many industries, it lends itself to co-operative ventures.

The third stage of economic development differentiated above, implies radically different scientific needs. During this stage, where exports of consumer goods provide the main thrust for expansion, comparative advantages are to be realized not merely through natural resource endowments and cheap labour, but particularly by means of specialist labour skills and well-developed technology.[1)]

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1) This aspect was touched upon in Chapter 2, Sub-section 2.3 C.

In this stage of development manufacturing industry is expected to produce articles with the correct balance of novelty quality and price to compete effectively on world markets. The ability to innovate as well as to invent becomes therefore of overriding importance. And, in so far as this is stimulated by science, it can be said that the research needs of the economy increase.

According to our overall hypothesis this stage is also associated with the development of own production processes, as substitutes for imported production processes, to meet more exactly the unique requirements of the exporting industries. This then is the stage of import substitution in capital good manufacture.

It is a feature of a country in this stage of economic development that its industrial expansion is spear-headed by a group of corporations with an extremely high propensity to innovate. So for instance, the German chemical company, Bayer, claims that 62 per cent of the company's sales at present consists of products developed over the past two decades.[1)] The British Company, Imperial Chemical Industries, experiences a similar phenomenon. In this company ... "40% of sales in 1966 were in products unknown 25 years earlier".[2)]

Apart from the few highly research intensive sectors, spear-heading the economy, it is also a feature that other sectors strive to keep abreast of the latest developments and technology by creating research and other facilities whereby they can recognize developments elsewhere and through which they can generate their own technological

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1) Time (Atlantic edition), September 13, 1968, p. 66.

2) PRINZ, Wolfgang: Chemical research in South Africa. Technical report submitted for the M.B.A. degree, Cape Town, 1968 (Graduate School of Business, University of Cape Town) p. 42.

advances. This is reflected in relatively high (in terms of world standards) research ratios for virtually all sectors of the economy.

When the rôle of science in the economy is defined in this way, it becomes clear that the organizational structure of industrial research has to change. Competitive research, rather than co-operative research, is now the keynote.

Having looked, very briefly, at the various phases of economic development and at the general level of research activity associated with each, we may now turn to a closer examination of the present stage of economic development in South Africa and of the level of scientific activity properly associated therewith.

B. Present stage of economic development in South Africa

We will not attempt to evaluate, de novo, the present stage of economic development in South Africa, but will turn for guidance to a study by T.A. du Plessis[1], dealing with the industrial growth pattern and forces of economic expansion in South Africa. In this study du Plessis uses a model to determine, with the aid of input-output analysis, the effect of four causal factors in transforming the South African industrial structure over the period 1916/17 - 1956/57. These four factors are:

(i) Final domestic demand.

(ii) Exports.

(iii) Import substitution.

(iv) Technological change.

The method used to calculate the impact of each of these four factors during a given period is, briefly, as follows.

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1) DU PLESSIS, T.A.: The industrial growth pattern and the real forces of economic expansion in South Africa, 1916/17 - 1956/57, Pretoria, 1965 (Thesis submitted at the University of South Africa for the D.Com. degree).

First, final domestic demand. The magnitude of its impact is calculated as the difference between, on the one hand, the actual level of final domestic demand at the end of the period, and on the other hand, the level of final domestic demand at the beginning of the period multiplied by the average rate of expansion in the gross domestic product.

Second, exports. The magnitude of this force is calculated as the difference between the actual level of exports at the end of the period on the one hand, and on the other, the level of exports at the beginning of the period multiplied by the average rate of expansion in the gross domestic product.

Third, import substitution. The effect of this force is obtained by deducting the imports at the beginning of the period from the imports that would have occurred if the import coefficient observed at the terminal date had applied at the beginning of the period, and multiplying the difference obtained by the average rate of expansion in the gross domestic product (and, finally, changing the sign of the product).

Fourth, technological change. This is calculated as the change in intermediate demand. The first step here is to multiply the input coefficients ruling at the beginning of the period with the output of the relevant section at that stage, thus obtaining the actual total intermediate demand at the beginning of the period. From this is subtracted the input ccefficients ruling at the end of the period multiplied by the output of the relevant sectors at the beginning - thus obtaining the intermediate demand that would have been realized if the output coefficients of the second date were applicable at the first. The next step is tc multiply this difference by the proportionate growth factor and to change the sign of the product.

The results obtained by du Plessis are presented in Table XVIII.

TABLE XVIII[1)]

PERCENTAGE SHARE OF VARIOUS CAUSATIVE FACTORS IN THE TRANSFORMATION OF THE INDUSTRIAL STRUCTURE OF THE SOUTH AFRICAN ECONOMY FOR VARIOUS PARTS OF THE OVERALL PERIOD 1916/17 - 1956/57

FACTOR	1916/17 - 1956/57	1926/27 - 1956/57	1936/37 - 1956/57	1946/47 - 1956/57
Final domestic demand	32	22	26	33
Exports	30	28	19	12
Import substitution	22	36	44	38
Technological change	16	14	11	17

From the above du Plessis concludes that: ... "since the thirties import substitution has contributed the dominant single growth element in the process of industrialisation. At the same time the export of manufactures, and changes in technology, although of less quantitative importance, also made a distinct contribution to the more than proportionate expansion of the economy. Import substitution, remains, a major potential source of industrial growth as long as the supply of mineral resources lasts and the domestic need for agricultural products do not exceed local production".[2)]

The above analysis suggests that South Africa is at present in the second phase of economic development as identified by Akamatsu. Exactly how far South Africa has progressed in this phase and when it will embark upon the third phase of economic development - if it has not arrived there already - is difficult to say. It is generally realized that the third phase will be forced upon the Republic sooner than expected, as the relative

1) Ibid., p. 136, 158, 173, 175, 190.

2) Ibid., p. 234.

diminution - to be followed by an absolute reduction - in gold exports shifts the burden of earning increasing amounts of foreign exchange to the manufacturing sector, with the consequent onus on this sector of strengthening its technological ability. (This aspect will be more fully dealt with in Chapter 5.)

Having established that the Republic is at present in the second stage of economic development and having investigated the research requirements of an economy during this stage, we may now proceed with a more detailed analysis of the actual research features of various economic sectors in the country.

4.3 The structure of research and development in South Africa and other technological features of the South African economy

A. Research intensity of the South African economy

(a) Absence of highly research intensive sectors

In the previous Section it was suggested that a country in the second stage of economic development could not expect to possess the type of highly research intensive sectors which spear-head expansion, to the same extent that countries in the third stage of development could be expected to. This notion seems to be borne out by the data in Table XIX, which shows expenditure on applied research and development in South Africa, classified in terms of the thirty-four sectors of the South African economy, and expressed as a percentage of each sector's contribution to gross domestic product.

This table may be compared with the data presented in Chapter 8, Sub-section 8.3 C(b), which shows the existence of highly research intensive sectors such as aircraft and missiles and instruments, which is a feature of the United States, German and French industrial scenes. These sectors are not differentiated in South African statistics as they have not, as yet, assumed sufficiently significant economic proportions.

Another feature which emerges from Table XIX is the relative unimportance, in the case of South Africa, of an electronics industry. This is a fairly highly research intensive industry and explains a considerable part of the relatively high research ratios observed for the sector electrical machinery in overseas countries. No doubt, the rapid expansion of an electronics industry in South Africa will eventually lead to an increase in the research ratio for the sector

TABLE XIX

EXPENDITURE ON RESEARCH AND DEVELOPMENT BY GOVERNMENT AND OTHER EXPRESSED AS A PERCENTAGE OF EACH SECTOR'S CONTRIBUTION TO GROSS DOMESTIC PRODUCT

Sector of the economy	Contribution to gross domestic product	Expenditure on research and development by government	Expenditure on research and development by government as percentage of contribution to gross domestic product	Expenditure on research and development by others	Expenditure on research and development by others as percentage of contribution to gross domestic product	Total expenditure on research and development	Total Expenditure on research and development as a percentage of contribution to gross domestic product	Ratio of research performed within the government to research performed elsewhere
	R Million	R	%	R	%	R	%	
1. Agriculture, forestry and fisheries	850.9	10,265,091	1.2	1,119,305	0.1	11,384,395	1.3	9.2
2. Gold mining (including uranium)	607.8	810,026	0.1	2,039,794	0.4	2,849,820	0.5	0.4
3. Coal mining	64.4	18,535	..	417,336	0.7	435,871	0.7	..
4. Other mining and quarrying	307.6	555,073	0.2	808,347	0.2	1,363,420	0.4	0.7
5. Processed foodstuffs (excluding beverages)	144.9	413,709	0.3	109,023	0.1	522,732	0.4	3.8
6. Beverages and tobacco	45.8	233,569	0.5	136,890	0.3	370,459	0.8	1.7
7. Textiles	71.6	290,643	0.4	13,040	..	303,683	0.4	22.3
8. Knitting mills	20.0	1,250	..	-	-	1,250	..	
9. Clothing	67.8	1,250	..	-	-	1,250	..	
10. Footwear	26.7	1,250	..	41,500	0.2	42,750	0.2	..
11. Wood and wood products (excluding furniture)	34.3	176,777	0.5	-	-	176,777	0.5	
12. Furniture and fixtures	42.9	1,874	..	-	-	1,874	..	
13. Pulp and paper products	61.7	70,242	0.1	99,100	0.2	169,342	0.3	0.7
14. Printing, publishing and allied industries	57.5	1,470	..	16,163	..	17,633	..	0.1
15. Leather and leather products (excluding footwear)	5.8	6,635	0.1	43,500	0.8	50,135	0.9	0.2
16. Rubber products	29.3	1,250	..	361	..	1,611	..	3.5
17. Basic industrial chemicals	47.8	80,949	0.2	1,141,391	2.4	1,222,340	2.6	0.1
18. Miscellaneous chemical products	56.6	125,321	0.2	289,742	0.5	415,063	0.7	0.4
19. Products of petroleum and coal	57.2	22,310	..	427,646	0.8	449,956	0.8	0.1
20. Non-metallic mineral products	82.6	60,783	0.1	818,338	1.0	879,121	1.1	0.1
21. Basic iron and steel industries	129.9	52,785	..	870,259	0.7	923,044	0.7	0.1
22. Non-ferrous metal basic industries	20.3	133,275	0.6	15,131	0.1	148,406	0.7	8.8

NOTE: The notation - indicates that the value is 0.

The notation .. indicates that the value is less than half of one unit of the measure employed.

Sector of the economy	Contribution to gross domestic product	Expenditure on research and development by government	Expenditure on research and development by government as percentage of contribution to gross domestic product	Expenditure on research and development by others	Expenditure on research and development by others as percentage of contribution to gross domestic product	Total expenditure on research and development	Total expenditure on research and development as a percentage of contribution to gross domestic product	Ratio of research performed within the government to research performed elsewhere
	R Million	R	%	R	%	R	%	
23. Metal products (excluding machinery and transport equipment)	166.5	10,727	..	111,206	0.1	121,933	0.1	0.1
24. Machinery (excluding electrical machinery)	99.0	111,041	0.1	12,021	..	123,062	0.1	9.2
25. Electrical machinery and equipment	51.5	205,502	0.4	417,805	0.8	623,307	1.2	0.5
26. Transport equipment (excluding motor vehicles)	32.1	242,100	0.8	12,243	..	254,343	0.8	19.8
27. Motor vehicles	59.0	1,250	..	56,911	0.1	58,161	0.1	..
28. Miscellaneous manufacturing industries	31.8	58,793	0.2	136,063	0.4	194,856	0.6	0.4
29. Construction	401.2	740,568	0.2	247,228	0.1	987,796	0.3	3.0
30. Electricity, gas and water	168.4	2 167,353	1.3	82,706	..	2,250,059	1.3	26.2
31. Trade (wholesale and retail)	1,130.5	47,241	..	-	-	47,241	..	
32. Motor trade and repairs	90.8	2,094	..	-	-	2,094	..	
33. Transport and communication	613.9	158,836	..	18,656	..	177,492	..	8.5
34. Miscellaneous services	1,813.3	1,250	..	3,524	..	4,774	..	0.4

NOTE: The notation - indicates that the value is 0.

The notation .. indicates that the value is less than half of one unit of the measure employed.

electrical machinery and equipment - that is if the South African industry requires as high a research input as its overseas counterparts. But for the present this has not yet occurred..

(b) General low level of research and development ratios

From Table XIX it can be seen that the research intensive sectors in the South African economy with the highest research rating are: basic industrial chemicals, whose expenditure on research amounts to 2.6 per cent of value added; non-metallic mineral products, whose research ratio amounts to 1.1 per cent; products of petroleum and coal, with a research ratio of 0.8 per cent; coal mining, with a research ratio of 0.7 per cent; basic iron and steel industries, with a research ratio of 0.7 per cent; and electrical machinery and equipment, with a research ratio of 0.6 per cent.

When these ratios are compared with those for overseas countries, the relatively low research endowment of South African industry becomes apparent. A research ratio of 1 to 2 per cent for the chemical industry in South Africa, compares with ratios ranging from just over 2 per cent in the case of Italy, to ratios in the region of 14 per cent in the case of Belgium and the Netherlands. The ratio of 0.7 per cent for basic iron and steel industries in South Africa compares with ratios ranging from 0.9 per cent in the case of the U.S.A. to over 4 per cent in the case of the Netherlands.

In one case a South African research and development ratio compares fairly well with those observed overseas. This is the non-metallic mineral products sector, whose research ratio of 1.1 per cent falls within the range observed for the five European countries, namely 0.8 per cent to 5.9 per cent. On the whole, however, relatively low research ratios characterize the South African economic scene.

(c) Low industrial participation and high government contribution

Another feature of economically orientated research and development in South Africa is the high government contribution. This is also depicted in Table XIX which expresses research undertaken by government bodies on behalf of various sectors of the economy as a percentage of each sector's contribution to gross domestic product; and next to that the expenditure on research and development undertaken by all other bodies, again expressed as a percentage of each sector's contribution to gross domestic product.

It will be noted that in the sectors agriculture, forestry and fisheries, textiles, non-ferrous metal basic industries, electrical machinery and equipment, transport equipment (excluding motor vehicles), and electricity, gas and water, the ratio frequently exceeds 5 and even assumes values of over 20 in certain cases. In these sectors research work undertaken by the government significantly affects the research and development ratio.

The conclusion may be reached therefore that not only is the research input of South African industry proportionately lower than in the highly industrialized countries, but that it is also less direct in the sense that so little is undertaken within industry itself.

B. Other technological features of the South African economy

(a) South Africa's technological gap

It has been a feature of recent literature on problems of international trade in Europe, that much attention is given to the concept "technological gap".[1] The fear apparently, is that America with

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1) See for instance The Economist, "The technological gap", March 16, 1968, pp. 71 - 76; and RICHARDSON, Jacques: "Why Europe lags behind", Science and Technology, no. 77, May 1968, pp. 20 - 29.

its enormous research potential will generate such a technological capability that it will acquire a dominant position in inventive ability, and therefore be able to dictate to Europe (and the world) the terms under which products and processes developed in America may be sold and exploited by others. Fears loom large in Europe that this will give rise to firstly, excessive service payments to the United States, in the form of patent fees and royalties, and secondly, limitations on manufacturing freedom imposed by the American patent holder.

South Africa seems to have been less concerned with this problem, partly because of the security the Republic enjoys as a result of its gold, and partly because international competition in manufactures has not, as yet, emerged as a crucial active factor in South Africa's economic advance. Nevertheless, indications of a technological drift, leading to a potential gap between South Africa and the industrially more sophisticated countries, are emerging, with the consequent danger which this spells for the future of South African manufacturers and their attempts to export abroad. Two indicators may be used, namely, the rate of invention and the brain drain.

(i) Rate of invention

If the rate of invention in a country is measured by the number of domestic patents per thousand of the population, a figure of .06 is obtained for South Africa. 1)

Rates for other countries are: Belgium, 0.59; Czechoslovakia, 0.52; France, 0.29; Germany, 0.20; Britain, 0.20; U.S.A., 0.20; and Japan, 0.16. Two countries have invention rates similar to South Africa; namely Australia, 0.08; and Canada, 0.05. However, both the latter two countries have taken

1) SHIPMAN, John R.: "International patent planning", Harvard Business Review, vol. 45, no. 2, March-April, 1967, Exhibit 1 facing page 56.

special steps to strengthen their industrial research capacity - as we will have occasion to point out.

(ii) Technological balance of payments

The second indicator of a technological gap is the technological balance of payments, or, in other words the difference between payments for licence fees, royalties, and technical information; and the receipts on account of these items.

It is estimated that South Africa pays approximately R20 million per annum to overseas companies for this purpose. This amount excludes payments on licences for trade marks for consumer products. The estimate of R20 million was obtained by a sample[1)] of all companies performing research. It was assumed that their share in total technological payments made by South Africa was the same as their share in total industrial employment. The sample data were then appropriately inflated to obtain the overall estimate for South Africa.

To the extent that the companies sampled were research intensive and, therefore, prone to buy technical information, the estimates may be taken as too high. On the other hand, it may be argued, that all the companies sampled had their own research laboratories and could, possibly, be less reliant on overseas technical information than other industries in the Republic which do not have their own research facilities. If this is the case the estimate is too low.

In contrast to the R20 million paid by the Republic she probably received less than R1 million on the same account - estimated in the same manner as payments were estimated.

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1) Information gathered in the course of the survey of expenditure on research and development in South Africa for the financial year 1966/67 and the academic year 1966.

(b) Brain drain

Although much is written in the popular press about the brain drain from South Africa, very few statistical data are available to indicate the extent to which this phenomenon occurs. A recent study undertaken by a Committee of the United States Congress would seem to contain the latest data available.[1)]

This study shows that during the year ended June 30, 1967, seventy-four engineers, scientists and medical personnel from the Republic of South Africa settled in the United States. To evaluate this figure, it is necessary for us to make a few calculations and comparisons.

First of all we have to find an estimate of the number of scientists working in South Africa. One investigator estimates 3,130.[2)] Let us furthermore assume that the growth rate in the scientific population is in the order of 15 per cent per annum or, in other words 470. This would imply that the brain drain to the United States alone is equal to approximately 16% of the annual increase in scientists, engineers, and medical personnel. But this is only a first approximation. Many of the engineers and physicians who emigrated were professional men rather than true research workers. If we estimate that research workers and scientists contributed equally to the emigration flow, we may then concluded that 8 per cent of the annual increase in scientists emigrate to the U.S.A.

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1) UNITED STATES CONGRESS, HOUSE COMMITTEE ON GOVERNMENT OPERATIONS: The brain drain of scientists engineers and physicians from the developing countries to the United States, Washington D.C., 1968 (U.S. Government Printing Office), p. 96.

2) MASSON, D.R.: Personal communication. Data soon to be published as part of a study being undertaken by the Council for Scientific and Industrial Research of the:..."generation communication and use of information by research scientists."
See MASSON, D.R.: "The cycle of knowledge and scientific information usage patterns in South Africa", South African Journal of Science, vol. 63, no. 9, September, 1967, p. 395.

Unfortunately data in respect of other countries of destination are not readily available so that an estimate of the total emigration rate of scientists is very much in the nature of a guess. It may be put at something in the region of 15 per cent of the annual increase; where the annual increase provides for a certain volume of immigration as well.

It is difficult to evaluate this figure, based as it is on a whole range of assumptions. If more complete data had been available, one could possibly suggest that the rate of increase in the number of scientists could rise from 15 to 17 per cent by removing the incentives to emigrate - provided of course, this larger force could be absorbed. But under the present circumstances such a suggestion is unwarranted.

Finally, it should be reported that an attempt was made to calculate the net rate of migration of scientists. Due to problems with the data this did not succeed. The impression gained however, was that while there is a net outflow it is probably less than is generally assumed and that insufficient allowance is made for the significant inflow that takes place.

In general the above data on the research intensity of the South African economy and on certain technological features, substantiate the notion that South Africa is at present in the second stage of economic development and that the impact of research is of necessity somewhat limited. This hypothesis will be further investigated in the next Section in which a quantitative guideline about the economic effects of science will be sought.

4.4 Technological change in the South African economy and the importance of scientific research

A. Technological change in South Africa

(a) Overall technological change

An indication of technological change in South Africa provides the first quantitative boundary for an impression about the economic value of science.

At least two attempts at estimating the overall rate of technological change in South Africa are known. The first of these was undertaken by Enke[1] in 1962 while the second was undertaken by Fourie[2] who is in the process of publishing the results in a D.Com. dissertation.

According to Enke the average increase in gross value added by the modern sector of the economy (as opposed to the subsistence sector) is approximately 3.7 per cent per annum of which 1 per cent, as he puts it, ".... might stem from advances in the state of arts".[3] This must be regarded as an extremely rough estimate.[4] According to this author, therefore, the third factor is responsible for approximately 27 units out of every 100 units of growth. The Enke estimate is open to some question however, as it is based on certain preliminary calculations and on a relatively short term snalysis of a decade, namely 1950 to 1960.[5]

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1) ENKE, Stephen: "South African economic growth: a macro-economic analysis", South African Journal of Economics, vol. 30, no. 1, March 1962, pp. 34-43.

2) FOURIE, L.J.: Die bydrae van die onderskeie produksiefaktore en produktiwiteitsverandering tot ekonomiese groei in Suid-Afrika. D.Com. dissertation in preparation. University of the Orange Free State.

3) ENKE, op. cit. p. 40.

4) Ibid., p. 38.

5) See for instance the comments of GRAAFF, J. de Villiers: "Alternative models of South African growth", South African Journal of Economics, vol. 30, no. 1, March 1962, pp. 44-49.

The most thorough estimate of technological change in South Africa has been undertaken by Fourie on the basis of whose calculations we may estimate that increases in labour and capital account for approximately 59 units out of every 100 units of growth while the third factor is responsible for 41 units.

However, it must be stressed that Fourie's calculations involve the solution of a simple production function in which technological change is isolated as the residual. His estimates are, therefore, subject to the same qualifications as specified in Chapter 2 Sub-sections 2.2 A and 2.2 C

Details of Fourie's calculations are presented in Table XX which shows not only the index of the contribution of various growth forces to growth in overall product but similar details for the various sectors of the economy as well.

TABLE XX

INDEX OF CONTRIBUTION OF INCREASES IN LABOUR AND CAPITAL, AND OF THE RÔLE OF THE THIRD FACTOR, TO ECONOMIC GROWTH IN THE REPUBLIC OF SOUTH AFRICA 1920/22 - 1958/60.

SECTOR OF THE ECONOMY	INDEX OF CONTRIBUTION		
	Increase in labour	Increase in capital	Rôle of third factor
Agriculture and forestry	- 2.7	46.9	55.8
Mining and quarrying	31.6	28.8	39.6
Manufacturing	48.4	27.0	24.6
Other	34.5	28.9	36.6
TOTAL ECONOMY	29.6	29.5	40.9

This table is based on a more comprehensive table calculated by Fourie and the data have been adjusted to correspond to a method of presentation used in earlier chapters of this dissertation. Fourie, for instance, calculates the contribution of white and non-white labour separately and also tries to account for increases in land use (or rather natural resources) which is of particular importance in the mining industry. In the above table the impact of increase in natural resource utilization has been included with the third factor, as is customary in calculations for overseas countries, and the impacts of white and non-white labour have been added together.

(b) Technological change in agriculture

The only estimate of technological change in agriculture which could be traced is that of Fourie's. According to his calculations, the increase in output per unit of input accounted for just under 56 units out of every 100 units of growth while the increase in capital accounted for 47 units. Because of the migration of (especially white) manpower from the agricultural sector to other sectors, the change in manpower has a negative influence of nearly 3 units out of every 100 units of growth. To the extent that manpower in agriculture declined, the most important growth forces obviously lie elsewhere.

(c) Technological change in mining

Again the only estimate of technological advance in the mining sector is that undertaken by Fourie. According to his calculations the growth in the third factor explained just under 40 units out of every 100 units of growth, while the growth in inputs explained approximately 60 units. In Fourie's original calculation the third factor is broken down into increased utilization of natural resources and other influences, the former factor accounting for 23 units out of the total of 39 units constituting the third factor.

(d) Technological change in industry

Two estimates are available of technological change in manufacturing industry. The first is that of Fourie while the second is the result of a study undertaken in the U.S.A. According to Fourie, the rôle of the third factor was responsible for approximately 25 units out of every 100 units of growth during the period 1920/22 - 1958/60.

The second estimate stems from work undertaken by Bergman[1] for the period 1955 to 1964. He holds the third factor responsible for 47 units out of every 100 units of growth while labour and capital together are responsible for 53 units.

This discrepancy was discussed with Fourie who suggested that one possible cause thereof could be the fact that he (Fourie) used a more up-to-date and possibly more accurate time series of aggregate product than Bergman. For the record it is interesting to note that Fourie's[2] own estimates for the contribution of the third factor to the growth in manufacturing industry, show that it is even less in the latter period (1947/49 - 1958/60) than over the long period (1920/22 - 1958/60). This contrasts significantly with the conclusion by Bergman.

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1) BERGMAN, Leslie F.: "Technological change in South African manufacturing industry", South African Journal of Economics, vol. 36, no. 1, March, 1968, pp. 3 - 12.

2) FOURIE, op. cit. personal communication.

(e) Technological change in other sectors

According to Fourie's estimate the rôle of the third factor is responsible for nearly 37 units out of every 100 units of growth.

(f) Comment

When comparing the extent of the third factor influence in South African economic growth with the values discussed in Chapter 2 Section 2.2 for a whole range of countries, we come to the conclusion that the magnitude of the third factor in South Africa corresponds more to the third factor values for five Southern American countries studied than to the third factor values for more advanced groups of countries.

For the five Southern American countries third factor values were calculated for four sub-periods each. Of the twenty results obtained six values exceeded the South African value while fourteen were exceeded by it.

In one sample of more advanced countries (numbering eleven), seven countries had third factor values exceeding that of South Africa. Of the remaining four (Netherlands, Israel, Japan and Canada) only Canada had a third factor value significantly lower than the South African value.

As far as the second sample of advanced countries is concerned (which also contained a number of countries included in the first sample), nine countries were distinguished and third factor values calculated for three sub-periods in each case. Of the twenty-seven values obtained only one was lower than the South African value. All the other values exceeded the South African value - most by a significan margin.

With this additional perspective we may now proceed to the final phase of our investigation of the importance of science to the South African economy.

B. The importance of science

In this, the final part of Section 4.4 we will present various examples of scientific research which has led to obvious economic advantage. This presentation will, it is hoped, assist in illustrating the commercial success of science in various economic settings.

At the outset, however, a few comments are called for.

Firstly, this Sub-section was intended as an encyclopaedic review of economically successful research in South Africa. However, it was found that satisfactory data in this connection are extremely hard to come by. Very few cases of economically successful scientific discoveries in South Africa have been adequately documented[1], and consequently only a limited number are presented. Information was obtained on certain other scientific achievements, but usually this information was so sparse, or required so many additional assumptions, that an economic evaluation comparable to those presented seemed unlikely. It was felt that these additional studies would contribute only marginally to the insights gained from those actually presented.

Secondly, the examples to be presented should by no means be considered the most outstanding examples of economically successful research. It is the opinion of the author that some of the most remarkable scientific achievements (in an economic sense) in South Africa have occurred where research has been undertaken in fields vital to the establishment of an economic

1) A search through the South African Journal of Science of the past fifteen years yielded three examples (to be discussed below); through Tegnikon (the new series), one example (also to be discussed below) and through the South African Journal of Economics during the past two decades, none.

infrastructure. Examples are available from the fields of water research, road research and building research, but because the benefits from these fields are so diffused throughout the economy it is difficult to evaluate them with the required degree of accuracy. Examples of research on rock stresses in deep level mining, on aspects of fisheries processing, on leather processing and the manufacture of leather goods, and on sugar manufacture, all appear to have yielded significant economic returns, and it is believed that further studies in these areas could uncover yield patterns of even greater magnitudes than those that will be presented below. Also, of course, there are examples within private industry - but these are usually known to a very small circle only.

Finally it must be mentioned that one of the biggest stumbling blocks for studies of this nature is commercial and official secrecy. It was acutely experienced by the present author and will no doubt affect future studies in this field as well.

With these few comments we may now turn to a discussion of individual examples of economically successful research projects.

(a) Examples of the impact of science on agriculture[1)]

(i) The elimination of livestock diseases

The progress of animal husbandry in South Africa is closely associated with the activities of Arnold Theiler, a young Swiss Veterenarian who arrived in the old South African Republic in 1891. Early in 1896, news was received in Pretoria of a devastating epizootic of rinderpest approaching from the North. Theiler was summoned by President Kruger and sent to Rhodesia

1) Valuable assistance rendered by officials of the Department of Agricultural Technical Services in the preparation of this Sub-section is recorded with appreciation.

to investigate the report. During the next two years Theiler devoted a large part of his energies in combating the epizootic and together with other research workers succeeded in developing an effective method of immunizing cattle against rinderpest.

Unfortunately their success came too late to avert the full blow of the catastrophe and 95 per cent[1] of the South African cattle stock was killed. However, scientific insight into the causes of rinderpest had been gained, and steps could be recommended to avert future catastrophies of this nature. This was probably one of the most significant developments in the growth of the South African cattle population which attained a level of approximately 12 million head by the late 1940s.[2]

Horse sickness was another of the major diseases which were curtailed by Theiler's activities. This disease was encountere by the early Cape Settlers and probably existed in East and North Africa before the seventeenth century. The disease was enzootic in many of the more sub-tropical parts of the country and periodically severe epizootics would sweep over almost the entire country. In one such outbreak 40 per cent of the total horse-population is reported to have died.[3] During the period 1905-31 Theiler and others succeeded in developing a polyvalent vaccine which radically diminished the impact of horse sickness in South Africa. While in the context of modern

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1) ALEXANDER, R.: "Onderstepoort, die stryd duur voort", Scientia, vol. 9, no. 7, July, 1968, p. 8.

2) DU PLESSIS, S.J.: "Groei en leef (vooruitgang in die Republiek van Suid-Afrika op die gebied van landbou, bosbou en visserye) Suid-Afrikaanse Akademie vir Wetenskap en kuns, Referaat 47, 1965.

3) DEPARTMENT OF AGRICULTURAL TECHNICAL SERVICES: Memorandum by Dr. R.Alexander. (Mimeographed) (Undated)

technology, this development might not be fully appreciated, it was an important step in maintaining a large portion of the country's traction power in the period before the advent of mechanization.

A final example of the impact of scientific research on the progress of animal husbandry concerned the curtailment of ngama. This disease was widespread throughout Transvaal, Swaziland and Zululand towards the ènd of the nineteenth century. It is transmitted by the tsetse fly and while it primarily affects domestic animals, game animals act as carriers thereof. While the disease gradually disappeared from (apparently) natural reasons in the Transvaal and Swaziland, a small locus of infection remained in Zululand at the end of the previous century.

Zululand was considered ideal cattle country except for ngama, which made farming in the area virtually impossible. For many years attempts to control the disease by trapping of flies and systematic game eradication were unsuccessful. A large part of the natural resources of South Africa therefore, remained unexploitable because man had not yet learned to conquer nature there.

In 1945-46 a disastrous epizootic broke out and the disease spread far beyond its normal confines. Over an area of 500 square miles at least 60,000 deaths among cattle were recorded. It was found that drugs could be applied with some success but it was apparent that complete eradication of the fly was the only final solution to the problem. At that stage the necessary chemical spray, in the form of DDT, had become available and aerial spraying was a practicable feasibility - but the success of this method depended entirely on knowledge of the life cycle of the tsetse fly and of breeding areas. As a consequence of careful scientific study this knowledge became available and effective spraying of the tsetse fly could take place.

The economic effect hereof, was that 7,000 square miles of excellent grazing country were made available for cattle farming It is difficult to place a monetary value on this acreage - all that can be said is that the economic contribution is approximately equal to the value of the land (as grazing area) less the cost of spraying and the negligible value of the land as a useless terrain.

Another side effect of, possibly, great potential economic significance, (although it may not be recognized as yet) is the fact that game could be preserved which otherwise would have had to be eradicated.

(ii) Locust control

As in the case of animal husbandry, the cultivation of crops in South Africa has been rendered more economic by the contribution of scientific research. By the control of locusts alone it is estimated that crops to the value of R50 million are presently saved in those years in which locust outbreaks would have occurred.[1)]

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1) "It is estimated that if this work were to be given up, at least 25 million pounds worth of crops would be destroyed in any one locust year". SMIT, Bernard: "Fifty glorious years of co-operation in scientific researcl in Southern Africa", South African Journal of Science, vol. 56, no. 9, September 1960, p.205.

But this is only after the advent of effective control programmes made possible, inter alia, by scientific research, Benzene Hexachloride, better road transport, and the use of aeroplanes. With respect to the contribution of science it is said: "By this time, however, Professor Faure had published his paper on 'The Phases of Locusts in South Africa' and had shown that outbreaks originated from the so-called 'Veld Grasshoppers', those solitary locusts that everybody knew so well in the Karroo. The tide began to turn and locust control was based on proper scientific knowledge of the biology and life history of the pest."[1)]

Before this, (for instance in 1933) it is pointed out that £1 million was spent on "attempted control" (even then apparently not successful) and that an additional amount of £60,000 had to be paid out for stock losses caused by the poison.

(iii) Increase in sugar production

The cultivation of sugar cane is perhaps one of the finest (but by no means exceptional) examples of an increase in agricultural production brought about by the contribution of scientific research. Research aimed at understanding the conditions of soil and climate in which sugar cane thrives, understanding the way in which it is to be planted and cultivated to ensure that the maximum amount can be produced without giving rise to growth inhibiting congestion and without over-taxing the soil, understanding which pests attack it and what deterrents restrain these, and many other questions, has caused an increase in the

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1) Ibid., p. 205.

production of cane from 2.05 tons of sugar per acre harvested, to 4.43 tons.[1)]

In more aggregate terms, this implies that the sugar production of 1.3 million tons in 1964 would only have been 0.6 million, if new knowledge (arising mostly from scientific research) had not become available to the sugar industry. According to the author the surplus revenue brought about by this increased production, amounted to R67 million in the short space of 30 years.[2)]

Of course one has to make allowance for technology imported from abroad (if any) and for the cost of applying new knowledge in practise, before attempting to calculate the approximate economic return to science. If we assume, for the sake of argument, (and this is only a rough approximation) that 1/3 of the "gross benefit" is ascribable to knowledge introduced from abroad, and that 1/3 of the "gross benefit" was absorbed by the cost of applying new know-how, then the net benefit attributable to South African science would amount to approximately R22 million in the case of sugar production.

A (high) estimate of the cost of research over 30 years would be about R5 million. Consequently research in this specific sector seems to have "paid off" in the ratio of $4\frac{1}{2}$:1.

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1) LLOYD, Anson: Sugar's response to the challenge of science, <u>South African Journal of Science</u>, vol. 60, no. 1, January, 1964, p. 50

2) Ibid., p. 50.

(b) Examples of the impact of science on mining

(i) Research on the human element[1)]

While the mining industry in South Africa offers a number of examples of technological research yielding high economic returns, one of the most significant impacts which scientific research has had on the mining industry is in connection with the improvement of health of mine-workers and the consequent decrease in mortality and morbidity as a result thereof.

It has been pointed out that in the period 1900-1910 the death rate due to disease amongst Bantu mine-workers amounted to 32 per thousand workers per annum. (By comparison the accident rate amounted to 6 per thousand per annum). In 1914, Dr. A.J. Orenstein, advocated medical research on mine-workers and headed one of the first units in this connection. Due to his efforts, as well as those of others, the death rate dropped in the period 1910-1920 to 14 deaths per thousand workers per year due to disease.

It is interesting to note that the accident rate was also reduced to 3 workers per thousand workers per annum. In 1920-1930 the mortality rate as a result of disease was reduced by a further 30 per cent to 10 workers per thousand workers per annum. This rate has been significantly reduced since then, and at present is well under 2 workers per thousand workers per annum.

During the 1960's the death rate due to disease among Bantu mine-workers dropped below the figure for mortality due to

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1) Information presented in this Sub-section was obtained almost exclusively from; HILL, F.G.: Productivity in the gold mining industry, paper read to the Productivity Conference, Pretoria, 24 - 26 October, 1966, held under the auspices of the South African Bureau of Standards.

accidents. Diseases accounted for 1.9 deaths per thousand workers per year, while accidents accounted for 2.5 deaths per thousand workers per year. Much of the decline in the rate of deaths stemming from disease is specifically attributed to medical research.

Also it is reported that "absenteeism due to disease and accidents has reached the remarkable low figure of 1.5 per cent, which is roughly half that of the European labour force".[1]

(c) Examples of the impact of science on manufacturing industry

(i) The "Tellurometer" system

One of the most interesting innovations based on research conducted in laboratories in South Africa is the Tellurometer system of distance measurement by radio. In the tenth annual report of the Council for Scientific and Industrial Research, namely for the year 1954 to 1955, the first reference is given to the system. "The possibility of precise distance measurement by radio for survey purposes has been investigated and preliminary indications are that an instrument devised in the Laboratory will enable this to be done with great accuracy. The method is attractive when compared with the conventional method...".[2]

In the following year the annual report comments: "The 'Telluro-meter System' of distance measurement, developed in the Laboratory, has proved, in a series of field tests, that for geodetic purposes the original specification of an accuracy of one in

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1) Ibid., p.20

2) COUNCIL FOR SCIENTIFIC AND INDUSTRIAL RESEARCH: Annual Report 1954-1955. Pretoria, 1955 (CSIR), p. 90.

100,000 (e.g. one foot in 20 miles) has been exceeded by a fair margin. The equipment is light in weight, easy to operate and relatively robust. Its development has aroused considerable interest from survey authorities throughout the world, as considerable effort has been devoted to this problem in overseas countries during the past few years without success".[1)]

At that stage arrangements were concluded with an instrument manufacturing firm, namely, Instrument Manufacturing Corporation of South Africa Limited, to manufacture and sell the system under licence. The CSIR Annual Report for the period 1957 to 1958 comments on this: "Production of the instrument by Tellurometer (Pty.) Limited in association with the CSIR has continued. The instruments manufactured in Cape Town have been sold throughout the world, many now being in use in the United States, the Continent of Europe, Australia, Canada, and the Middle East. Others have been exported to Japan, India, South East Asia, Venezuela and other South American countries".[2)] Subsequent annual reports tell of the development of associated systems and imply continued commercial success of the family of systems as a whole.

The following extract from the annual report of the Instrument Manufacturing Corporation of South Africa Limited, indicates the extent to which a key scientific discovery leading to commercial success generated a number of products which had not existed before:

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1) COUNCIL FOR SCIENTIFIC AND INDUSTRIAL RESEARCH: Eleventh Annual Report 1955-1956, Pretoria, 1956 (CSIR), p. 94.

2) COUNCIL FOR SCIENTIFIC AND INDUSTRIAL RESEARCH: Thirteenth Annual Report 1957-1958, Pretoria, 1958 (CSIR), p. 134.

"TELLUROMETER PROJECTS

These projects are handled through the medium of Tellurometer (Pty.) Limited a wholly owned subsidiary, which holds certain Patent and other licences from the South African Council for Scientific and Industrial Research.

The main projects of interest are:-

1.1 'Micro-distancer' - a radio distance measuring device for use in geodetic and other types of land survey. A new model (Model MRA 3) has recently been introduced which has found a keen demand by Government and other survey agencies throughout the world, notwithstanding a fairly considerable measure of competition.

1.2 'Hydrodist' - a radio device for the precise positioning of ships at sea as in marine survey, hydrography, etc. This equipment is also in use in many parts of the world.

1.3 'Aerodist' - a radio device for long range extension of survey control - it has the capability of measuring distances up to 300 miles with an accuracy of a few metres - and for positioning an aerial survey aircraft at the instant an aerial photograph is taken, as an aid in preparation of maps in photogrammetry. Certain overseas Governments are finding this equipment of great use in their mapping tasks.

1.4 'Terrafix' - this is a multi-user, hyperbolic type of equipment designed for use as a navigating or positioning aid by military personnel in the field. Its development and design has recently been accomplished and the first system was sold during the year under review. It is hoped to sell several other systems in the immediate future.

1.5 'Hydrofix' - this is a multi-user, hyperbolic system similar to Terrafix but designed for use by ships. It is still in the development stage and it is too early to say to what extent that it will add to the general activity of this subsidiary".

Further, the report goes on to acknowledge the contribution which the CSIR continued to make to the company's commercial success.

"The rapid growth of your Company, representing as it does a somewhat complex Group organization, which operates in a world wide and highly technical field, justifies our making special reference to contributory factors.

In the first place the continued success of the "TELLUROMETER" Project is without doubt due to the assistance rendered by the National Institute for Telecommunications Research of the South African Council for Scientific and Industrial Research. Our liaison with the CSIR helps greatly to improve the technical level of work within IMC".[1)]

As may be expected, detailed figures of production costs, costs of research and development, sales, and profits are hard to come by; and consequently it is not possible to discuss extensively the return on research expenditure in connection with the tellurometer project. However, data which have been entrusted to the author, indicate that, if net profits are assumed to reflect the return on investment in research, the

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1) INSTRUMENT MANUFACTURING CORPORATION OF SOUTH AFRICA LIMITED, Annual Report, Cape Town, 26th November, 1963.

rate of return is in the order of 50 per cent per annum and possibly higher.

(ii) The manufacture of cement from blast furnace slag

Another research success with a significant economic impact was the discovery (through carefully conducted scientific research) that properly treated slag, from South African blast furnaces, can be used as an ingredient in the production of cement.

Not that the use of blast furnace slag in cement production is unknown. Research, conducted mainly in Germany, led to the realization that slag can be effectively mixed with Portland cement provided the slag is properly treated beforehand. This had led to the production of what is called in Germany; "Hochofenportlandzemente" and "Eisenportlandzemente".

The problem in South Africa is that dolomite is used in the blast furnaces instead of lime (which, in Europe is more conventional). Dolomite has a high magnesium content and in all other spheres of cement manufacture this magnesium content is regarded as highly undesirable. In terms of accepted industrial know-how the use of blast furnace slag in cement manufacture was not considered feasible.

After investigating this premise the CSIR determined that, in spite of its high magnesium content, properly treated blast furnace slag could be added to Portland cement without detracting unduly from its various functional qualities. (Hardening times were longer, but the strength of the final product seemed to be higher).

The economic benefits arising from this research is of a dual nature.

First, blast furnace slag is essentially a waste product with no alternative uses. It has to be transported away from the blast furnace in a red hot molten state and merely dumped. Because of the large volume of slag forthcoming from the iron production process (approximately half a ton of slag for every ton of iron) the slag dumps soon become enormous unsightly heaps occupying valuable industrial land - and this land is virtually unreclaimable for industrial use. If the slag could be used as an industrial raw material, the economic liability of slag heaps could be avoided.

Second, it is known that the cost of extending a Portland cement plant (in the capacity range which prevails in South Africa) is of the order of R25 per additional ton of (annual) throughput. The cost to erect a slag treatment plant is of the order of R10 per ton of annual capacity. There is thus a potential saving in the capital cost coefficient of R15 per ton of plant capacity. During the past decade or so the demand for cement has grown at a rate of approximately 100,000 tons per annum. Applying the above saving in the capital cost coefficient to the said 100,000 tons implies a saving of R1.5 million per annum.[1)]

If the full saving is taken to represent a return on the scientific research performed, an annual yield of several hundred per cent is obtained.

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1) STUTTERHEIM, N.: "Sement uit hoogoondslak". <u>Tegnikon</u>, vol. XIV, no. 3, September 1965, p. 89.

(iii) Developments in the treatment of sewage effluent

Not all research leads to commercial success in glamorous fields of application. Sometimes very mundane tasks benefit from the contributions of scientists. So, for instance, one may cite the example of an activated sludge system for sewage purification which was developed by the National Institute for Water Research of the CSIR on the basis of an idea conceived by a waste disposal engineer. The patents which were awarded as a result of this development work are held by the South African Inventions Development Corporation and further refinement to the process is still being undertaken. Details of the process are explained in a booklet issued by the South African Inventions Corporation.[1] According to latest reports, the system is being well received and profits in the first year were such as to reflect a hundred per cent return on the investment in research by the National Institute for Water Research.

(iv) At the impressionitic level the example may also be quoted of companies such as Seravac Laboratories (Pty.) Limited in Cape Town which undertake highly specialized science based manufacture (in this case, of enzymes and related biochemical products) and which compete effectively in the international market.

To the economist interested in science the sales catalogue of this enterprise, with its carefully documented scientific references, provides a startling example of just how far

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1) SOUTH AFRICAN INVENTIONS DEVELOPMENT CORPORATION: A guide to the use of the Huisman orbal activated sludge system for sewage purification, Pretoria, 1968 (South African Inventions Development Corporation).

individual enterprises in South Africa have exploited the economic promise of science.

But this is a rare example.

C. The economic impact of science in South Africa - a final comment

To form a final overall impression about the economic impact of science in South Africa, and to summarize this Chapter, the following six points may be noted.

(i) In terms of the wild-geese-flying-pattern theory of economic growth, South Africa is at present in the second stage of economic development. During this stage an economy does not appear to depend as heavily on domestic science as countries in later stages of development.

(ii) For the financial year 1966/67 the aggregate research ratio for the Republic was calculated at 0.5 per cent of gross domestic product. This level was probably only recently achieved and in all likelihood amounted to no more than 0.3 to 0.4 per cent in 1960 and 0.1 to 0.2 per cent in 1950.[1)]

(iii) The limited impact of the low aggregate research ratio is probably even more curtailed by the relatively low research expenditure of the non-government sector and in particular the manufacturing sector (when compared to the government sector).

(iv) Manufacturing industry in South Africa would seem to rely very heavily on the importation of foreign technology.

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1) It was estimated at one sixth of 1 per cent in 1944. See COUNCIL FOR SCIENTIFIC AND INDUSTRIAL RESEARCH: Objects and policy of the CSIR: An initial statement, op. cit., p.6.

(v) The value of the third factor in South Africa is generally lower than the third factor in the more advanced countries, and it may be suggested that the impact of research, as one of the forces of the third factor, is, as a consequence, lower as well. A maximum estimate for the contribution of domestic science would therefore be substantially less than 20 units out of every 100 units of growth.

(vi) Finally, in spite of the above, case studies of economically successful scientific research indicate that carefully executed research in South Africa can yield an economic return which at times is of an order of magnitude higher than the rate of return usually expected from investment in capital goods. This indicates that while science may not be regarded as a significant force in the total economic scene in South Africa, it does nevertheless, in certain circumstances cause a tremendous economic impact.

At this stage it is appropriate that we ask: What about the future? We attempt to answer this question in the next Chapter.

5. SCIENCE AND THE FUTURE ECONOMIC DEVELOPMENT OF SOUTH AFRICA[1)]

5.1 Introduction

In the last Chapter it was argued that South Africa is currently in the "second stage" of economic development, namely the stage of "import substitution". It is also suggested that in this stage of development the research orientation of the country would reflect the need for adapting to local conditions production processes introduced from abroad. In the "third stage" of development the research needs would be different and geared to improving the country's competitive ability - especially in the export of products containing a large element of innovation. In this Chapter we will look more to the future economic development of South Africa and to the research structure which is properly associated therewith.

As may be expected, this Chapter is essentially an exercise in conjecture and therefore not susceptible to strict scientific, methodology. Nevertheless it remains an inescapable part of our field of enquiry covering economic aspects of scientific research in South Africa.

In the course of this Chapter it will be argued that South Africa will have to face the economic problems brought about by the saturation of import substitution possibilities (especially in the manufacture of consumer goods). Furthermore the potential decline in gold production and, to a lesser extent, the limits to growth in wool output, imply certain fundamental changes in the structure of economic activity. All these developments suggest a different pattern of research requirements and for this certain recommendations are then made.

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1) In writing this Chapter I have incurred an immense intellectual debt to: Mr. D.G. Kingwill, Director, Information and Research Services, Council for Scientific and Industrial Research; Dr. R. van Houten, Head, Technica Information Service, Council for Scientific and Industrial Research, and Mr. J.H. Visser, Director of Productivity.

5.2 Expected developments in the economy

A. A limit to import substitution?

It is a doctrine of economic growth theory, especially of the "wild - geese flying - pattern" variation, that import substitution of consumer goods as a growth force has a limited potential.[1)2)] (There remains, of course, the possibility of substituting imported capital goods with those of local manufacture. But this really coincides with the third stage during which consumer goods have to be exported and production processes have to be developed locally to meet the requirements of the exporting industries).

The question which may now be asked, and which is of vital importance in selecting a future research strategy, is whether the industrial growth potential provided by import substitution can still provide a major basis for development in the case of South Africa, or whether it has already been exhausted.

Unfortunately the results of an investigation dealing with this very question are not yet available.[3)] However, du Plessis, in his study previously referred to, offers the following indication: "Import substitution, remains, a major potential source of industrial growth as long as the supply of mineral resources lasts and the domestic need for agricultural products does not exceed local production".[4)]

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1) See AKAMATSU: op. cit. pp. 206 - 207.

2) However, a recent, more questioning attitude towards the exhaustion of import substitution industrialization should be noted. See in this connection : HIRSCHMAN, A.O.: "The political economy of import-substituting industrialization in Latin America". Quarterly Journal of Economics, February, 1968, vol. 82, no. 1, pp. 1 - 32.

3) SCHEEPERS, C.F.: Die invloed van invoervervanging op die omvang en samestelling van Suid-Afrika se invoere 1926/27 - 1963/64. D. Com. dissertation in preparation, University of the Orange Free State.

4) DU PLESSIS: op. cit., p. 234.

That author, therefore, sees the exhaustion of those primary products destined for export (and which provide the foreign exchange required to buy-in from abroad the production processes needed in import substituting industrialization), as the first limiting factor in the import substitution growth phase.

Not that he believes that import substitution possibilities per se are infinite, for he does concern himself at one stage with the: ... "time import substitution comes to wane as a relatively easy exploitable source of growth ....".[1)] But he does not see this as the proximate limiting factor in the import substitution growth phase. The reason, possibly, is that the author is not concerned with the distinction between consumer good manufacturing and capital good manufacturing. If he did draw this distinction he could possibly have identified the exhaustion of import substitution possibilities in the case of consumer goods, rather than limited exportable resources, as the first limiting factor in industrial expansion.

While it is at present difficult, if not impossible, to place a quantitative interpretation on du Plessis' guide line we know at least of two aspects which we now have to bear in mind. Firstly, there is a definite upper limit to import substitution possibilities in the case of consumer goods manufacture, and secondly, a reduction in the exports of primary products could adversely affect the supply of foreign exchange needed in the import substitution phase.

B. Significant trends in the production of economically important products

Apart from the general analysis in the Sub-section above, two specific trends also reveal themselves at present. These are:

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1) Ibid., p. 235.

(i) The relatively slow growth in gold production during the next few years and the subsequent decline during the next few decades.

(ii) The relatively slow growth in the production of wool in the near future.

(a) Expected trends in gold output

Since the publication of the report of the Gold Producers Committee of the Transvaal and Orange Free State Chamber of Mines,[1] dealing with various aspects of gold mining in South Africa and discussing the possible implications of a reduction in gold output, a number of estimates have been made of future trends in South African gold production.

One of the most comprehensive estimates was undertaken by Busschau, who, on the basis of various assumptions calculated the future gold production in the Republic.

On the assumption for instance that no significant quantities of new rich gold-bearing ore will be discovered, that there will be no increase in the price of gold, and that production costs will increase in the order of 2 per cent per annum - which may be regarded as a low estimate; Busschau[2] calculates that gold output will decline to 20 million fine ounces by 1980. If we regard the above set of assumptions as plausible, and if we extrapolate further on Busschau's curve, we arrive at an estimate of 10 million fine ounces by 1990.

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1) TRANSVAAL AND ORANGE FREE STATE CHAMBER OF MINES, GOLD PRODUCERS COMMITTEE: The outlook for gold mining, Johannesburg, 1966 (Transvaal and Orange Free State Chamber of Mines).

2) BUSSCHAU, W.J.: "Future trends in world gold production", Mining Survey, no. 61, September, 1967, p. 19.

We may use this estimate as a basis for further calculations about the impact of a reduction in gold output on the future economic structure.

(b) Growth in wool production

Another expected trend in the South African economy which is of significance here, is the relatively slow growth in wool production during the next two decades.

From the unsure trend in production during the past five years (1962/63, R104.4 million; 1963/64, R127.9 million; 1964/65, R100.2 million; 1965/66, R115.6 million; 1966/67, R98.0 million)[1] and due to the continued competition from synthetic fibres (expanding at 15 per cent per annum),[2] it is estimated that wool production cannot expand at a rate in excess of 1 per cent per annum during the next two decades. This estimate has been referred to the South African Wool Board and is regarded as reasonable.

(b) Implications

While it would probably not be justified to maintain that these two trends in themselves imply the loss of one of the main conditions set by du Plessis for a continuation of the import substitution stage of development, (namely the condition that the supply of mineral resources lasts and that agricultural production exceeds domestic demand), they do indicate an erosion of this condition. Because of this, and because they are important in their own right, it is appropriate that the quantitative effects of these trends be examined in more detail.

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1) SUID AFRIKAANSE WOLRAAD: Jaarverslag 1966-67.

2) SUID AFRIKAANSE WOLRAAD: Jaarverslag 1967-68.

C. Quantitative effects of these trends

The method adopted to calculate the effect of these two trends is to extrapolate the economy along its present growth path and to calculate the implications thereof for the various sectors, bearing in mind that each sector has its own unique growth rate and that some sectors will have to grow faster than average to compensate for the slow growth in others.

We begin therefore with an estimate of growth in aggregate product and set the target date at 1990.

(a) Growth in aggregate product

In the study by Fourie previously referred to, the growth rate in the gross domestic product in South Africa over the period 1920/22 - 1958/60 amounted to 4.37 per cent. In the last (approximately) decade of this period the growth rate amounted to 4.71 per cent per annum.[1] In a study by Visser and Fourie the estimate of the future growth of the economy is 5.15 per cent.[2]

In the case of the first Economic Development Programme published by the Department of Planning,[3] projections of the economy were based on three growth rates, namely, 4.5 per cent, 5.5 per cent and 6 per cent. The growth rate which was eventually taken as the target rate was 5.5 per cent. In the case of the second Economic Development Programme the growth rate assumed was 5.4 per cent,[4]

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1) FOURIE, L.J., op. cit., Table 7.13

2) VISSER, J.H., and FOURIE, L.J.: Suid-Afrika in 1990, Pretoria, 1967 (Council for Scientific and Industrial Research). (Restricted circulation) p. 8.

3) DEPARTMENT OF PLANNING: Economic development programme for the Republic of South Africa 1964-69, Pretoria, 1964. (The Government Printer).

4) DEPARTMENT OF PLANNING: Economic development programme for the Republic of South Africa 1965-70, Pretoria, 1965. (The Government Printer), p. 5.

and in the case of the third programme, an overall growth rate of 5.5 per cent was used as a basis for projection.[1)]

In a recent study by Kuschke[2)] it is argued that an average growth rate of 5.7 per cent per annum as from 1964 to the year 2000 is feasible.

For the purposes of the present dissertation, two growth rates were chosen to project the economy to 1990, viz. 5.15 per cent and 5.5 per cent. In terms of these assumptions, the gross domestic product which was estimated as R7,107[3)] million in 1965 will grow to R24,950 million and R27,150 million respectively by 1990.

(b) The change in the sectoral origin of gross domestic product

Any estimate of the future composition of the gross domestic product is of course no more than a guess. In Tables XXI and XXII attempts are made to estimate the sectoral origin of gross domestic product in 1990 on the basis of various assumptions.[4)]

In the case of Table XXI two estimates are given of the sectoral origin of gross domestic product in 1990. These two estimates are for expected growth rates in domestic product of 5.15 and 5.5 per cent respectively. The other assumptions are:

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1) DEPARTEMENT VAN BEPLANNING: Ekonomiese ontwikkelingsprogram vir die Republiek van Suid-Afrika 1966-71, Pretoria, 1966 (Die Staatsdrukker), p.1.

2) KUSCHKE, G.S.J.: Manufacturing industry in South Africa internal background - present and future, Johannesburg, 1968. (Industrial Development Corporation Limited). (Mimeographed). Schedule C

3) DEPARTEMENT VAN BEPLANNING: Ekonomiese ontwikkelingsprogram vir die Republiek van Suid-Afrika 1966-71, op. cit. p. 25.

4) Ibid., p. 25 for 1965 data. Further breakdown estimated on the basis of data obtained from the South African Wool Board and data taken from the text of the Economic development programme.

TABLE XXI

SECTORAL ORIGIN OF GROSS DOMESTIC PRODUCT IN 1965 TOGETHER WITH TWO ESTIMATES OF SECTORAL ORIGIN FOR GROSS DOMESTIC PRODUCT IN 1990

(Under the assumption that Mining (other) expands sufficiently to compensate for the loss in gold production)

Sector	1965		1990 - first estimate			1990 - second estimate		
	Gross domestic product	Percentage of total	Gross domestic product	Growth rate	Percentage of total	Gross domestic product	Growth rate	Percentage of total
	(R m.)		(R m.)			(R m.)		
Agriculture (wool)	69	1.0	86	0.90	0.4	86	0.90	0.3
Agriculture (other)	617	8.7	1,647	4.00	6.6	1,647	4.00	6.1
Mining (gold)	603	8.5	181	-4.93	0.7	181	-4.93	0.7
Mining (other)	389	5.4	3,300	8.94	13.2	3,608	9.30	13.3
Manufacturing	1,961	27.6	7,559	5.54	30.3	8,380	6.00	30.8
Services	3,468	48.8	12,173	5.15	48.8	13,248	5.50	48.8
TOTAL :	7,107	100.0	24,946	5.15	100.0	27,150	5.50	100.0

TABLE XXII

SECTORAL ORIGIN OF GROSS DOMESTIC PRODUCT IN 1965 TOGETHER WITH TWO ESTIMATES OF SECTORAL ORIGIN FOR GROSS DOMESTIC PRODUCT IN 1990

(Under the assumption that Manufacturing expands sufficiently to compensate for the loss in gold production)

Sector	1965		1990 - first estimate			1990 - second estimate		
	Gross domestic product	Percentage of total	Gross domestic product	Growth rate	Percentage of total	Gross domestic product	Growth rate	Percentage of total
	(R m.)		(R m.)			(R m.)		
Agriculture (wool)	69	1.0	86	0.90	0.4	86	0.90	0.3
Agriculture (other)	617	8.7	1,647	4.00	6.6	1,647	4.00	6.1
Mining (gold)	603	8.5	181	-4.93	0.7	181	-4.93	0.7
Mining (other)	389	5.4	1,319	5.00	5.3	1,319	5.00	4.8
Manufacturing	1,961	27.6	9,540	6.52	38.2	10,669	7.10	39.3
Services	3,468	48.8	12,173	5.15	48.8	13,248	5.50	48.8
TOTAL :	7,107	100.0	24,946	5.15	100.0	27,150	5.50	100.0

(i) Output of the sector gold mining declines to such an extent that it will amount to no more than 10 million fine ounces by 199[illegible]

(ii) The sector agriculture (wool) grows at 0.9 per cent per annum;

(iii) The sector agriculture (other) grows at 4 per cent per annum - which is slightly higher than the growth rate assumed for this sector in the Economic Development Programme for the period 1966-71;

(iv) The sector services maintains a constant 48.8 per cent of gross domestic product;

(v) The production of the sector mining (other) will have to expand sufficiently to compensate for the loss in gold production.

Under these assumptions the sector mining (other) will have to expand at a growth rate of just under 9 per cent to ensure an aggregate growth rate of 5.15 per cent, and in so doing increase its share in aggregate product from 5.4 per cent to 13.2 per cent; while for the assumption of 5.5 per cent increase in aggregate product, the said sector will have to expand at 9.3 per cent and increase its share in total output to 13.3 per cent.

Two more estimates of what the sectoral origin of gross domestic product will be in 1990 are given in Table XXII. All the assumptions from (i) to (iii) which applied in calculating Table XXI apply here again. However, with respect to the sector mining (other) it is now assumed that this sector merely expands at a rate of 5 per cent which is approximately equal to the rate assumed in the Economic Development Programme for the period 1966-1971.[1] The growth rate

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1) Ibid., pp. 55 and 57.

of the sector manufacturing is then calculated as a residual growth rate sufficiently strong to ensure that the said sector makes up any deficiency in the growth rates of the other sectors in order to achieve aggregate increases in output of 5.15 per cent and 5.5 per cent respectively.

According to these assumption the sector manufacturing will have to grow at a rate of approximately 6.5 per cent to ensure a growth in aggregate product of 5.15 per cent and increase its share in gross domestic product from 27.6 per cent in 1965 to 38.2 per cent in 1990. For an aggregate growth rate of 5.5 per cent the sector manufacturing will have to grow at a rate of 7.1 per cent and increase its share in aggregate product to 39.3 per cent.

(c) Changes in the sectoral origin of exports

In Tables XXIII and XXIV four estimates are given of the sectoral origin of exports in 1990 based on different assumptions.[1)]

Table XXIII has been calculated on the basis of the following assumptions;

(i) The exports of the sector agriculture (wool) will increase at a rate of 0.9 per cent per annum, i.e.arate equal to the increase in the production of the said sector.

(ii) The exports of the sector agriculture (other) will increase at a rate of 5.5 per cent per annum. This is somewhat lower than the 8.5 per cent per annum employed in the Economic Development Programme 1966-71,[2)] but as the latter figure has

1) Ibid., p. 20 for 1965 data. Further data taken from the text of the Economic development programme and obtained from the South African Wool Board.

2) Ibid., p. 52.

TABLE XXIII

SECTORAL ORIGIN OF EXPORTS IN 1965 TOGETHER WITH TWO ESTIMATES OF SECTORAL ORIGIN FOR EXPORTS IN 1990

(Under the assumption that Mining (other) expands sufficiently to compensate for the loss in gold production)

Sector	1965		1990 - first estimate			1990 - second estimate		
	Exports	Percentage of total	Exports	Growth rate	Percentage of total	Exports	Growth rate	Percentage of total
	(R m.)		(R m.)			(R m.)		
Agriculture (wool)	112	5.4	140	0.90	1.9	140	0.9	1.8
Agriculture (other)	124	6.0	472	5.50	6.5	472	5.5	6.0
Mining (gold)	775	37.3	245	-4.71	3.4	245	-4.7	3.1
Mining (other)	391	18.8	3,837	9.54	52.6	4,197	10.0	53.0
Manufacturing	447	21.5	1,793	5.70	24.6	1,984	6.1	25.1
Services	228	11.0	803	5.15	11.0	875	5.5	11.0
TOTAL :	2,077	100.0	7,290	5.15	100.0	7,913	5.5	100.0

TABLE XXIV

SECTORAL ORIGIN OF EXPORTS IN 1965 TOGETHER WITH TWO ESTIMATES OF SECTORAL ORIGIN FOR EXPORTS IN 1990

(Under the assumption that Manufacturing expands sufficiently to compensate for the loss in gold production)

Sector	1965		1990 - first estimate			1990 - second estimate		
	Exports	Percentage of total	Exports	Growth rate	Percentage of total	Exports	Growth rate	Percentage of total
	(R m.)		(R m.)			(R m.)		
Agriculture (wool)	112	5.4	140	0.90	1.9	140	0.90	1.8
Agriculture (other)	124	6.0	472	5.50	6.5	472	5.50	6.0
Mining (gold)	775	37.3	245	-4.71	3.4	245	-4.71	3.1
Mining (other)	391	18.8	1,325	5.00	18.2	1,325	5.00	16.7
Manufacturing	447	21.5	4,305	9.46	59.0	4,856	10.00	61.4
Services	228	11.0	803	5.15	11.0	875	5.50	11.0
TOTAL :	2,077	100.0	7,290	5.15	100.0	7,913	5.50	100.0

been somewhat inflated to allow for a short term adjustment to normality in the agricultural sector which experienced a poor year in 1965, it was felt that a 5.5 per cent growth rate compared reasonably well with the recent average increase in production of 5.1 per cent per annum.[1)]

(iii) It is assumed that the entire gold production is exported and that the amounts available for export are the same as those calculated in the case of Sub-section 5.2 C (b) above.

(iv) The exports of the sector <u>mining (other)</u> will increase so as to offset the decrease in exports of gold.

The exports of the sector <u>manufacturing</u> are calculated as a residual and these grow at a rate which is sufficient to ensure growth rates in aggregate product of 5.15 per cent and 5.5 per cent respectively.

It will be noted that to offset the loss in gold exports the sector <u>mining (other)</u> will have to grow at a rate of 9.5 per cent to ensure an aggregate growth rate of the economy of 5.15 per cent and will have to increase its share in exports from 18.8 per cent to approximately 52 per cent. To ensure a growth rate of the total export bill of 5.5 per cent the sector <u>mining (other)</u> will have to expand at a rate of 10 per cent and increase its share in total exports from 18.8 per cent to 53 per cent.

If this happens the exports of manufacturing will have to expand at 5.7 per cent to ensure an expansion of the overall export bill of 5.15 per cent and a rate of 6.1 per cent to ensure an expansion of the overall export bill of 5.5 per cent.

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1) Ibid., p. 52.

In the case of Table XXIV the same assumptions listed from (i) to (iii) above, apply again. The only difference is that the sector mining (other) is assumed to expand at 5 per cent which, it may be recalled, is the same growth rate assumed for the overall production of the said sector. The exports of the sector manufacturing are calculated as a residual.

On the strength of these assumptions it may be calculated that the sector manufacturing will have to expand at a rate of approximately 9.5 per cent to ensure a growth rate in the overall export bill of 5.15 per cent and at the same time increase its share in exports from 21.5 per cent to 59 per cent. In the case of an increase of the export bill of 5.5 per cent the sector manufacturing will have to grow at 10 per cent and increase its share in the overall export bill of 21.5 per cent in 1965 to just over 61 per cent in 1990.

D. Concluding remarks

On the basis of the above analysis it may be observed that due to the relatively slow growth in the sector agriculture (wool), and the imminent decline in production of the sector mining (gold), the South African economy will be faced with certain structural problems.

To maintain the aggregate growth rate of somewhat more than 5 per cent (which has more or less become accepted as a conventional growth rate in South Africa) will require either a marked increase in production in the sector mining (other), or a relatively strong growth in the sector manufacturing, or possibly, some combination of these two. Projections of possible changes in composition of aggregate product suggest however that the demands which the said expansions will make on the economy are not unreasonable and could be met in the normal course of development.

However, when examining the impact of expected future developments in gold production and wool production on the total export bill it is clear that an exceptional compensatory economic performance will be required. Either the exports of the sector mining (other) will have to increase substantially or those of the sector manufacturing will have to – or, of course, a combination of both these two factors will have to occur. Whichever way the problem is looked at a special task for policy makers is indicated.

5.3 Steps to counteract undesirable developments

A. The encouragement of exports and the need for a technological build up

From the discussion in the previous Section it emerged that certain far reaching achievements will be called for of the South African economy during the next decade or so. A clear cut need exists for South Africa to develop some form of exports which will compensate for gold and wool.

The first logical place to look for exports which can fill (what is essentially) the gold gap, is in the mining of other minerals. This seems to be what many observers would expect - as the following extract may illustrate: "I suspect that in the next twenty years, metal mining may not be in for quite the rampaging world wide boom which some prophets aver, but I would also bet that the new mines opened in South Africa will be the ones least likely to lose money. Export revenue from base minerals as a whole will mount steadily, probably offsetting by itself the fall in revenue from gold".[1)]

Needless to say this point of view is strongly endorsed by the mining industry in South Africa. Arguments have been put forward that the manufacturing industry will not be able to expand rapidly enough to compensate for the loss of gold exports, but that this gap could quite readily be filled by expansion in mineral exports.[2)]

Not that growth in the export of manufacturers has not received any recognition. Exhortations from ministerial level have been frequent and no doubt a certain amount of soul searching has taken place within

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1) MACRAE, Norman: "South Africa the green bay tree : A special survey" The Economist, vol. 227, no. 6514, June 29, 1968, p. xliv.

2) See, for instance: Financial Mail, "After gold, the days of ore?", vol. XXIX, no. 7, August 16, 1968, pp. 551 - 552; and Financial Mail, "Filling the gold gap", vol. XXX, no. 10, December 6, 1968, p. 983.

industry. But a general burning conviction that the manufacturing industry will save the day is not a feature of current economic thought in South Africa. So, for instance, du Plessis believes: "By the time import substitution comes to wane as a relatively easy exploitable source of growth, it is sure that new comparative advantages in skill and technology would have been developed in local manufacturing industry, with the result that it can be anticipated that manufacturing exports will forge ahead as a more prominent causal factor of growth. It is doubtful, however, whether exports of either resource or technology oriented manufactures could ever assume the historical and strategic rôle played by primary exports in South Africa's foreign trade and in the direct stimulation of the country's economic development".[1)]

To an extent this qualified pessimism is understandable. South Africa is in many respects an industrial dependency of major British, European and American interests and without the necessary foundation for economic nationalism so characteristic of Germany and Japan. Furthermore the target growth rate in the export of manufacturers, i.e. a growth rate of some 9 or 10 per cent, is high, and virtually double the growth rates which have occurred in the recent past. Also, it must be remembered, that this target growth rate is an average growth rate, implying that many industries will have to increase their exports at rates far in excess of 10 per cent per annum - say in the region of 20 per cent or so.

It would seem unwise, however, to rely too exclusively on the mineral resource potential to fill the gold gap in exports. It may be pointed out for instance that the very proponents who argue that manufacturing industry is incapable of meeting the additional export responsibility, and suggest

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1) DU PLESSIS: op. cit., p. 235.

that it is up to the mining industry to do so, find it necessary to call for government support and to propose a system of mining subsidies. Of course, this has evoked a certain amount of criticism of which the following may be regarded as typical: "Short-term, some or all of this may be needed. But, as for serious forward planning, it would be better to drop this negative approach and concentrate on exploration, advanced mining methods, modern transportation facilities, and marketing".[1)]

Quite apart of the need for government subsidies for the mining industry, the mere quantitative increase in the production of the sector mining (other), which would be required to take up the unfilled share in aggregate product occasioned by the slow growth in the sector mining (gold), is large. The rate of growth (see Tables XXI and XXII, Chapter 5, Sub-section 5.2 C (b) required is approximately 2.5 percentage points higher than the growth rate which would be required of the sector manufacturing, if it had to produce the compensating growth.

For the above reasons, as well as others, a school of thought has developed which would ascribe a much more than secondary rôle to manufacturing industry in filling the gold gap in exports. Quite apart from the vested interests of organized industry, this school of thought has found support from a number of persons associated with industrial research in South Africa.[2)3)]

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1) Financial Mail, "Filling the gold gap", vol. XXX, no. 10, December 6, 1968 p. 983.

2) NAUDÉ, S. Meiring: Today's laboratories, to-morrow's gold mines, Scientiae vol. 9, no. 12, December 1968, pp. 9 - 12.

3) VAN WYK, R.J.: Research and development as a source of technical informatio for industry, Paper 16 of the Southern Africa regional symposium on scientific and technical information, organized by the South African Council for Scientific and Industrial Research and the Assoçiaçao Industrial de Moçambique, Lourenço Marques, 2 - 5 July, 1968.

Essentially they argue that it is the task of South African manufacturers to develop products with a sufficient quantum of technical novelty to give them a competitive superiority in international trade. (In essence this confers a quasi-monopolistic advantage on the said manufactures). This argument is reinforced by references to the source of export power in the U.S.A., Britain and Germany (see Chapter 2, Sub-section 2.3 C) and by pointing to the few examples of science based achievements by South African industry (see Chapter 4, Sub-section 4.4 B (c).

On balance it is difficult to establish clear cut preference between manufacturing and mining (other). What is certain is that if either of these two sectors accept the challenge of filling the gold gap in exports, it will require a structural re-organization. In the case of manufacturing a much increased technological capability will be called for - whether to develop new products or to process and export existing products more efficiently; and in the case of mining (other) the need will exist to develop the most economical techniques of mining, transporting overland and shipping abroad. Whichever way, the need for the most advanced technology conceivable is apparent.

B. Technological build-up and the importation of technology

Many sectors of the South African economy have for a long time now relied almost exclusively on imported technology. With this we mean the production under licence of articles developed abroad, and the use of equipment and processes patented elsewhere. Notable exceptions are the sectors mining and agriculture where home grown technology has played an important part.

The use of imported technology offers many advantages. The most important probably being the fact that it has been tried and tested and that it is in a sense, ready made. Against these benefits the cost of importing technology appears minimal, and manufacturers have accepted this cost, in the form of royalties, patent fees and licence monies, willingly.

For a country in an "import substitution" stage of development, reliance on foreign technology is probably the most obvious method of operating. All that is required is to shift the locus of manufacture for a given product from some country abroad, to a domestic site. This can usually be accomplished without significant difficulties. Problems may exist in adapting foreign production processes to local conditions, but these problems are usually readily overcome.

Frequently, also, local manufacturers enter into technical know-how agreements with foreign enterprises, which entitle the local enterprise to technical advice from the foreign company, as well as to an automatic option on all new products developed by the foreign concern.

In practice these procedures seem to work well for the less technologically sophisticated types of processes and products. Licence fees are usually minimal compared with the cost of the equipment and payments under technical know-how agreements also appear fairly moderate.

However, once more sophisticated products and processes are dealt with the importation of foreign technology can become a more costly affair. The original developer (the foreign enterprise) has to recoup a larger investment in research and development[1)] and consequently his royalties,

1) See in this connection Table XXVII, Sub-section 8.3 C (b).

licence fees, and levies under technical know-how agreements, are correspondingly inflated.

This introduces a different economic dimension. The importation of technological know-how becomes that much more expensive and the relative economic merit thereof a little more open to question.[1)]

Furthermore, licence agreements frequently stipulate; (i) that the licensee is restricted to the domestic market and may not compete internationally with the licensor; (ii) that the licensee is only entitled to produce the "first generation" products and that the manufacture of "second genration" products should be provided for in a new agreement; and (iii) that all product or process improvements effected by the licensee automatically become the property of the original patent-holder. Under such conditions any incentive for the licensee to innovate is largely removed.

For a country, such as South Africa, entering the "third stage" of economic growth and wishing to develop a technological capacity as a basis for a major long term export drive, the excessive reliance on foreign technology would appear to be of questionable wisdom. Some thought should be given therefore to the development of a domestic technological potential in addition to that which can be obtained from abroad. It is not suggested that domestic technology can replace foreign technology entirely, but the call for an increased contribution by home grown technology does seem justified.

The obvious question to be asked at this stage is; How is a domestic technological build up encouraged. Will it call for, inter alia a

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1) At present it is estimated that royalty payments, licence monies and payments under technical know-how agreements cost the Republic R20 million per annum. Approximately R1 million is received on this account. See Chapter 4 Sub-section 4.3 B.

contribution from domestic science, concentrated, say, in fields of relevance to the export of manufactured goods and base minerals?

It may be useful to gain some impression of developments in countries abroad which are faced with similar or somewhat similar problems to South Africa.

C. Development of domestic technology - examples from abroad

As soon as a particular attempt is made to find examples of science being employed to build up a country's export strength, the literature yields some interesting comments.

Firstly, a number of countries seem to be preoccupied with the need for establishing and encouraging export industries. The policy of Japan, it is reported in passing .... "is to tailor industrial effort to the prospective demand of markets overseas."[1)] And Britain, it is noted, acclaims any industry which promises a major contribution to exports.[2)]

Secondly, explicit references are found to countries which have decided to build a scientific basis for industry as part of their long term export plans. Israel may serve as one example. This is a relatively small, rapidly developing semi-industrialized country with latent balance of payments problems which could possibly become acute once the German reparation payments diminish or cease. (This particular balance of payments position is very similar to that of South Africa's - with the expected reduction in gold output). Recent reports on Israeli attempts to meet these problems show that it is the intention of that country to establish an industrial base drawing heavily from scientific discoveries. According to the report

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1) Nature, "Making way for innovation", vol. 219, no. 5161, September 28, 1968, p. 1296.

2) HARDS, Ken: "Today's machine tools and to-morrow's: The makings of an export boom?", New Scientist, vol. 39, no. 604, 4 July, 1968, pp. 13 - 15

"None of this means that Israel is about to take on Du Pont, Boeing, or RCA. With an annual gross national product of about $4 billion, the country simply does not have the resources to be competitive in most large markets. Instead, many firms have adopted the strategy of finding an area that has been overlooked, or deliberately bypassed by large American and European firms, and then exploiting it.[1]

The paper goes on to outline some of the directions which science based industry will probably follow. "Similarly, many electronics firms hope to concentrate on the manufacture of small instruments. And highly specialized pure chemicals, used in small quantities in laboratory work in various parts of the world, can profitably be produced in Israel because the final product is so expensive that the extra transportation costs from Israel are insignificant." The article then mentions the increased government expenditure on research within industry but gives very little detail of the programmes developed in this connection.

Two other countries which have taken significant steps in this direction are Canada and Australia. Both of these have tried to encourage a scientific and technical awareness within industry. Of the two the Canadian scheme is the better documented and the following features have emerged from a study thereof.[2] In Canada three incentives have been established to encourage industrial research and development. These are:

(i) A system of income tax provisions known as "General Incentive for Research and Development" (GIRD).

(ii) An "Industrial Research Assistance Programme" (IRAP).

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1) SAMUELSON, Robert J.: "Israel: Science based industry figures large in economic plans", Science, vol. 160, no. 3830, 24th May, 1968 , p. 864.

2) SHOWALTER, H.A., "Government support of industrial research and development in Canada", Research Management, vol. X, no. 1, January, 1967, pp. 51 - 60.

(iii) A "Programme for the Advancement of Industrial Technology" (PAIT)

Briefly the GIRD allows an immediate tax deduction of 100 per cent of capital and current costs which exceed the corresponding costs in a base year. In addition to this cash grants or credits against tax liabilities of 25 per cent on defined research and development expenditures are allowed.

IRAP is intended as an incentive for industries to expand their research facilities with emphasis on the staff factor. Companies which increase their research staffs to undertake new projects may apply for grants equal to the salaries of the new research workers. In practice this means that approximately 50 per cent of the additional cost of undertaking research is financed from government sources.

PAIT has the object of encouraging the development of marketable product and processes. Assistance under thisscheme is granted by the Department of Industries which evaluates applications in terms of costs, estimated market potential and technical feasibility. Grants equal to the running expenditure of the development work may be awarded. If the development work is successfully carried through these grants are repayable to the Department at a prescribed rate of interest and over a prescribed time. If the development work does not yield a marketable product, funds do not have to be repaid, but then all rights arising from any discoveries made in the course of the investigation revert to the government.

As the Canadian schemes in particular seem to be of interest to South Africa, it is appropriate that their impact be examined in a little more detail. While favourable reports have, in general, been received as to their influence, the following points of criticism should be noted as well.[1)]

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1) Nature, "How Canadians decide what to do", vol. 220, no. 5164, October 19, 1968, pp. 218 - 219.

First, it is claimed that assistance for current research takes too long to be worked out and paid.

Second, because profitable developments imply the repayment of the original grant, industries have developed the habit of postponing their applications as long as possible and then to claim on unsuccessful projects only.

Third, the requirement exists that the results must be applied in Canada. Consequently, foreign firms are not interested in the scheme. A further complication is that the government does not support the development of know-how which could find a ready market elsewhere.

To the author these difficulties do not seem serious enough to warrant the disqualification of the entire scheme. The first point concerning delays is probably no more than an administrative bottleneck. The second point concerning requests for assistance which only arise in those cases where the development work has turned out to be of no consequence, is admittedly somewhat distracting to the administrators of the scheme, but it does emphasize that inducements to undertake development do exist under the scheme. The final objection, namely that the results must be applied in Canada, seems to warrant reconsideration. Possibly allowance could be made for the utilization of research and development results abroad (at a fee of course), provided that the programme of government support be limited only to companies with a given minimum Canadian participation.

With these qualifications in mind we may now formulate specific suggestions for South Africa.

5.4 Suggested government action

Having established the need for improved sources of domestic technology (as a base for future export success) in South Africa, and having examined certain examples from overseas in this connection, we are now in a position to evaluate the present South African research endowment and to recommend certain changes.

A. Type of facilities required

Two major features of the South African research and development scene would seem particularly relevant to the present analysis.

Firstly, the concentration of research and development effort in the government sector, and the corresponding low level of activity in the business enterprise sector.

Secondly, the concentration of research and development effort towards the research rather than the development end of the spectrum.

These two features suggest that a possible deficiency exists in the sphere of industrial research[1)] in South Africa. Seen against the need for strengthening industrial technology in the Republic, it is appropriate to suggest specific action to overcome this deficiency.

While it is realised that the CSIR has certain responsibilities towards industry and is willing to undertake research and development on behalf of industry, this type of research service cannot adequately meet the full range of industrial needs. Normal institutional discontinuities frequentl hamper the effective communication of industrial needs or research findings

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1) Industrial is here used in its broader context and includes manufacturing as well as the extractive industries.

(Usually it is found that industry requires a certain scientific absorbtive capacity in the form of highly trained scientific or technical personnel, to overcome these difficulties). Furthermore the need for extremely strict commercial security gives rise to reservations within industry as to the wisdom of "contracting out" certain projects.

Also the creation of co-operative research organizations for industry possibly under the auspices of the CSIR does not promise unqualified success. Although the CSIR has been encouraging attempts in this direction since its foundation[1)] the establishment of such institutes has not progressed significantly after the 1940's.

The most appropriate action would seem to be the creation of research and development facilities within industry. This should enable industry to undertake research and development of its own accord, and in addition to this absorb more effectively the results of research emanating from other organizations. Not only should this contribute to the strengthening of the country's technological base, but also to a better utilization of other domestic research facilities and to a more efficient exploitation of foreign sources.

Finally it should be pointed out that the President of the CSIR has recently urged steps in this direction[2)] and that a former Minister of Planning has also spoken out in favour of research within industry: "In achieving these aims a powerful research programme would be essential; the Government is anxious to help with research facilities and by the integration of private research".[3)]

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1) COUNCIL FOR SCIENTIFIC AND INDUSTRIAL RESEARCH, and FEDERATED CHAMBER OF INDUSTRIES: Industrial research associations, Pretoria, 1948 (CSIR)

2) NAUDÉ, S. Meiring: "Today's laboratories, tomorrow's gold mines", op. cit. pp. 10 - 11.

3) Reported in: MAVROCORDATOS, C.E. "Progress in iron and steel making", Scientific South Africa, vol. 3, no. 1, November, 1965, p. 638.

B. Specific recommendations

Having recognized the need for encouraging the establishment of in-house research facilities within industry the first question which should be decided is whether it would be appropriate to adopt schemes of direct support for industrial research and whether it would not be more suitable to incorporate the necessary incentives into the system of taxation, i.e. by tax allowances.

A careful balancing of pros and cons seemed to indicate however, that a direct government support for industrial research is the more preferable approach. Tax allowances have the disadvantage that their effects are extremely general and insufficiently localized to identify the exact nature of their benefits. Also it is difficult to assess the cost to the State of taxation allowances. A further disadvantage is that claims for tax rebates are difficult to administer as every claim would probably have to be certified by competent government research personnel. This administration could of course be lessened if the allowance for expenditure on research were exactly the same as the allowances for expenditure on other necessary production costs, but then the whole object of the allowance is lost and no particular incentive exists for an organization to perform research rather than purchase readily available know-how.

On the other hand a number of arguments may be raised lending weight to a system of direct government support. Firstly, the expected expenditure can be adequately and very precisely budgeted. Secondly, the impact of government support occurs exactly where planned, usually where the ideas are, in contrast to the support derived from tax allowances which usually accrues to those organizations sufficiently wealthy already to perform research and thus to gain from tax advantages. Thirdly, industry would probably prefer direct support, and fourthly, particularly in the case of South Africa, the necessary precedents exist for justifying direct government intervention. It is existing practice for government to make funds available for industrial research via the CSIR, on condition that the industrial research is of a co-operative nature and adequately sponsored by industry. The direct support of research activities within industry is in keeping with this principle, with the exception that the requirement that the research be of a co-operative nature is waived.

We may now look at the specific recommendations concerning two programmes which may be contemplated for South Africa.

(a) Programme for encouraging the establishment of industrial research facilities 1)

(i) Object

The object of this programme is to bring into existence teams of scientists performing research work within industry. The idea is to establish a level of technological competence which will enable industry not only to produce its own scientific discoveries (which it may then develop and eventually exploit commercially) but also to act as a listening post for scientific discoveries abroad, and in national institutes, which could possibly be of value to the industry concerned.

It is the task of these teams to interpret scientific trends and to present their interpretations in a frame of reference typical to the industry which they serve. In this way it is believed that science can be used to extend the technical possibilities which are known to management and thus increase the possibility of useful innovation.

1) This programme is in concept similar to the Canadian Industrial Research Assistance Programme discussed in Sub-section 5.3 C.

The object is essentially to increase the innovative potential of industry.

Care should be exercised however, for government not to over-commit itself on a programme of this nature and it should be an essential feature thereof that industry should share a significant portion of the costs. It could be suggested that government should be prepared to finance all expansion in personnel but that it should leave the financing of laboratory space and research equipment to the various industries being served. In effect this implies a system of scholarships for research workers with the proviso attached that these scholarships are tenable only in industry and not at universities. (No stipulations are made concerning the use of findings for academic purposes).

(ii) The magnitude of the programme

The cost of a programme of this nature would depend entirely on the desired effects which a country would like to achieve. In the case of South Africa we could start, for example, with the assumption that government is prepared to sponsor a five per cent annual addition to industrial scientific personnel. If it is assumed that a particular research worker will receive support for a period of 3 years it is possible to calculate the cost pattern of such a programme.

We begin with the figure of five hundred research workers in industry as estimated by Masson.[1] A five per cent increase in the first year would involve 25 research workers. In the

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1) Masson, op. cit., personal communication.

second year the government would again be responsible for these as well as an additional 26 research workers (i.e. 51 in total). During the third year funds would have to be provided for 28 "new" scientists in addition to the 51 continued from the previous year (i.e. 79 in total). During the fourth year 29 additional research workers may be financed, but at this stage the support of the original 25 ceases so that the total commitment will involve 83 research workers.

The cost of the programme in year n may be approximated by the formula:

$$C = E\left(S(1+r)^{n} - S(1+r)^{n-m}\right) \text{ subject to:}$$

$(n-m) = 0$ for all values $m > n$

and where : C = cost per annum

E = expenditure per research worker

S = number of research workers employed in industry at the start

r = desired rate of addition (percentage) to the research force,

n = number of years after start of programme

m = period, in years, for which support will be given to each individual research worker.

Assuming that the average cost per research worker amounts to R6,000 per annum, then the cost to the Republic of the said programme will be

1st year	R150,000
2nd year	R306,000
3rd year	R474,000
4th year	R498,000
5th year	R522,000

In other words just under R2 million for the first 5 years.

It must be pointed out however that because of the stipulation that industry should provide laboratory space and research equipment, the actual research effort generated by this government incentive of R2 million will be very much higher. On the assumption that salaries constitute 50 per cent of total cost the amount generated will amount to approximately R4 million.

(b) Programme for increasing the rate of development of advanced products and processes [1)]

(i) Objective

Whereas the previous programme was aimed at establishing a research (and thus technological) potential within industry the present programme is intended as an encouragement to the rate of successful developments.

It is intended as a programme whereby the government shares the financing of the cost of developing advanced products and processes, which share is eventually repaid by industry at an agreed rate of interest and over an agreed period if the development proves commercially successful. In those cases where the development does not bring commercial success the support monies are not repayable but all discoveries and research results produced by the industry responsible become the property of the government and are ceded to a government agency (e.g. the Inventions Development Corporation)

1) This programme is similar in concept to the Canadian Programme for the Advancement of Industrial Technology discussed in Sub-section 5.3 C.

(ii) Scope

It is difficult to suggest an appropriate figure for a suitable development fund. However, if we assume that an amount of R5 million is allocated for a five year period the following development programme could be contemplated:

One development project costing R1 million	= R1 million
Three development projects costing R0.5 million	= R1.5 million
Six development projects costing R0.25 million	= R1.5 million
Ten development projects costing R0.1 million	= R1 million
	R5 million

The question arises of course as to whether these allocations are worth while and whether the funds thus voted could possibly lead to any substantial developments. As a guide Table XXV is presented which shows the approximate threshold development costs of various electronic products as suggested by a team of the National Institute for Economic Research in Britain, and the annual research and development expenditure implied thereby.

These annual expenditures should be interpreted as: .... "the minimal level of R and D work in progress, sufficient to keep abreast of the technical changes in components, to introduce a flow of improvements and to launch completely new models when forced to do so by the competition."[1)]

1) FREEMAN, C., HARLOW, C.J.E., FULLER, Mrs. J.K., and CURNOW, R.C.: "Research and development in electronic capital goods", National Institute Economic Review, no. 34, November, 1965, p. 69.

TABLE XXV

NOTIONAL[a] EUROPEAN DEVELOPMENT THRESHOLDS AND LEAD TIMES

Product[b]	Notional threshold development cost (£'000)	Notional lead time (Years)	Derived annual R & D expenditure[c] (£'000)
Radio communications receiver	80 - 150	2	40 - 75
VHF transmitter	240 - 360	4	60 - 90
Laboratory oscilloscope	300 - 450	3	100 - 150
Marine radar set	100 - 2,000	3	33 - 66
Spectrum analyser	100 - 200	3	33 - 66
Machine tool control equipment	300 - 600	3	100 - 200
Small scientific computer	1,000 - 2,000	3	333 - 666
Research satellite	500 - 1,500	4	125 - 375
TV colour camera	1,600 - 3,000	4	400 - 775
Small quasi-electronic telephone exchange	2,000 - 4,000	5	400 - 800
Large fully electronic telephone exchange	6,000 - 9,000	6	1,000 - 1,500
Range of EDP computers, software and peripherals	8,000 - 16,000	4	2,000 - 4,000
Communication satellite	10,000 - 40,000	5	2,000 - 8,000

(a) Although these figures bear some relation to the actual orders of magnitude, they are not intended to be an accurate representation.

(b) Except in the case of computers, these are single products. In practice, of course, a firm would usually be involved in a range or in several products.

(c) Excluding pre-production expenses, investment in tooling, and market research.

This does not mean to say that South Africa should strive to develop the products which are presented in this table. It only serves to indicate the order of magnitude of development costs for various products.

(c) Comment

While it is believed that the programmes recommended above contain much merit and are worthy of consideration, it is realized that a number of points require further investigation before a final decision as to the desirability of the said programmes can be reached.

Firstly, a study will have to be made of the size composition of South African industry to determine whether sufficient industries exist which are large enough to sustain a viable research department.

Secondly, a study will have to be undertaken of the degree of foreign control in South African industry and a policy formulated as to which firms will qualify for assistance under the said programmes.

Finally, the extent to which the suggested programmes affect other aspects of government policy, will have to be determined. In particular attention will have to be given to government policy on size, merge and monopoly.[1)]

However, what it does suggest is that a whole range of development projects are within the capability of South African industry. Without claiming originality the following problems could be regarded as examples of the more expensive type of developments which could be contemplated: the development of a self-disintegrating container, such as could be used for beer, including bantu-beer; the development of a possible effective substitute for baby diapers; the development of breakproof crockery; and the development of lightweight material for setting fractures (as a substitute for "plaster of Paris"), such as, for instance, a quick-hardening foam which may be dispensed from a can, tube or aerosol spray.

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1) See in this connection: MANSFIELD, Edwin O.: "Size of firm, market structure and innovation", Journal of Political Economy, vol. LXXI, no. 6., December 1963, pp. 556 - 576.

These few examples may serve as a reminder that many inventions are at present just beyond the fringe of industry's scientific insight. If this is enhanced the rate of innovation in industry would more than likely increase markedly.

C. Concluding remarks

On the basis of a broad economic analysis, as well as an analysis of the South African research and development scene, recommendations have been formulated for matching the South African research and development effort more closely to the needs of the economy. In this connection some of the more obvious needs have been identified and explored in detail.

The steps recommended should not however be interpreted as the only means whereby science can assist in the future economic development of South Africa. Undoubtedly various other opportunities exist; but it is not possible to identify these in a broad study such as the present one.

Nevertheless it is appropriate that this Chapter be concluded with two remarks, inspired by economic considerations and relating to the government's research and development effort.

Firstly the high research intensity of the sector agriculture, forestry and fisheries calls for further examination.

The relatively high concentration of research funds in this field could possibly signify an over-allocation. At least it signifies a potential for increased efficiency through a (possible) better pattern of internal allocation among the various branchings of agricultural science.

Secondly, South Africa is faced with a number of generally recognized economic and social problems which are not always adequately reflected in overall economic analyses. These include :

(i) the limited future water resources in the Republic;

(ii) possibly limited future energy resources in relation to needs;

(iii) future housing needs;

(iv) the danger of congestion in the transportation systems (especially bearing in mind the policy of separate development) and

(v) the continued exponential rates of growth of the different population groups.

Some of these problems are already attracting much scientific attention while others are virtually ignored. It is believed that a thorough examination of the underlying causes of these problems is appropriate at this stage and that clear cut needs for scientific and technological contributions will emerge therefrom.

PART III

ECONOMICS IN SCIENTIFIC POLICY AND PLANNING

6. A MODEL FOR INCORPORATING ECONOMIC CONSIDERATIONS INTO SCIENTIFIC POLICY MAKING AT THE NATIONAL LEVEL

6.1 Introductory remarks

If it is true that a strong relationship exists between scientific research and economic growth, this link ought to be adequately reflected in the government policy-making process. In other words procedures should be created for integrating economic considerations into scientific policy-making, while economic policy makers should take account of developments in science which could affect the future of the economy.

In this Chapter we will take a closer look at the possibility of integrating economic considerations into the process of scientific policy-making. This is an ambitious undertaking, for the whole technique of constructing formal decision making procedures is still in its infancy.[1] Furthermore, the field of scientific policy-making is at present extremely nebulous in that no generally accepted classification of scientific policy issues exists. Inescapably, therefore, we will be drawn into an examination of these before we can consider the process of integrating economic criteria.

The basic approach will be to examine the possibility of constructing a simple decision making model. To this end we will discuss first, certain misgivings about the possibility of formulating a viable policy; second, key questions in scientific policy-making; and finally, the model itself.

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1) For a general review of this field see:
BAUER, Raymond A., and GERGEN, Kenneth J. (editors): The study of policy formation, London, 1968 (Collier-Macmillan Limited).

6.2 Misgivings about scientific policy making

A. Fundamental questions

Discussions on scientific policy frequently start with a semantic issue. The concept scientific policy, it is said, can mean either of three things. It can mean a policy for science. It can mean a policy for achieving given (extra-scientific) objectives by employing scientific means. Or it can mean any government policy scientifically worked out and formulated.

For the purpose of this dissertation we may ignore the third meaning entirely. The other two, on closer examination, turn out to pose, not a question of semantics, but of a basic policy attitude towards science. The question is: whether scientific policy should concern itself merely with the inner health of the scientific endeavour or whether it should be concerned with employing science for the benefit of society? That there is a conflict between these two is generally accepted. So Harvey Brooks maintains that over the short term; "The real issues involved in scientific planning mostly relate to how to reach the best adjustment between the need for science for internal autonomy and desires of society for the fruits of science".[1)]

At least one author, Thomas Kuhn,[2)] argues that the progress of science can only be adversely influenced when contaminated by an adherence to non-scientific goals. Kuhn is one of the few writers who has dealt with the internal process of scientific advance and, according to him, this process functions best when science is allowed to select its own avenues for further investigation.

According to Kuhn, a particular branch of science advances by a series of internal revolutions. Each revolution provides the scientific community

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1) BROOKS, Harvey: "Can science be planned?", in: ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT: Problems of science policy, Paris, 1968, (OECD), p. 97.

2) KUHN, T.S.: The structure of scientific revolutions, Chicago, 1962 (University of Chicago Press).

with a new paradigm, or in other words, with a new overall concept of whatever feature is being studied. Such a paradigm provides the broad perspective for studies of individual features falling within its scope and holds good as long as research, consistent with the general perspective of the paradigm, produces results which are mutually consistent as well. The appearance of inconsistent results suggests a crisis in the particular science and prepares the way for a revolution which is brought about by the establishment of a new paradigm. This process, Kuhn argues, is most perfect when science is allowed to select its own objectives and areas for investigation.

If the Kuhn thesis is extended to its ultimate extreme a case could be made out for claiming that scientific policy should be cast in terms of scientific objectives alone with very little, if any, provision for science as a means to (non-scientific) social ends.

This does not imply, however, that science should not be supported on the grounds of its extra-scientific consequences. In other words, government monies could be devoted to science because of its social value, but science should not be <u>planned</u> to serve social goals. In the framework of policy making this is tantamount to suggesting that science should be supported because of its potential contribution to a given social objective, say A, but that it should be allowed to proceed in terms of its own objectives, say B, with the expectation that the spin-off therefrom will ensure the achievement of A. This point of view is frequently implied in pleas by research workers in support of larger, unconditional, grants to science.

While few policy-makers support such an extreme attitude, their awareness of the problem is fairly general.[1)]

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1) See in this connection: PRICE, Don K.: <u>Government and science</u>, New York, 1962, (Oxford University Press), pp. 32 - 64, and also ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT: <u>Science and the policies of government</u>, Paris (?) 1963, (OECD).

B. <u>The boundaries of scientific policy</u>

Even if it is accepted that it is possible to employ science as a means to achieve social ends (and yet maintain its unique character), another problem, arising from the extremely wide social boundaries of scientific policy, presents itself.

Bearing in mind that: "science, as a social activity, is not self-contained"[1] and that it nourishes, and is itself replenished by social activities closely associated therewith, the thought arises that scientific policy should not be concerned with science alone but that it should also include those other associated social activities. Let us examine, therefore, the strength of these various associations.

(a) <u>Link with education</u>

First, there is the link between education and research. Here, two important ties exist. On the one hand the educational system "produces" the most important element in science, namely trained scientists. On the other hand it performs in its own right a very important part of the overall research and development effort. This follows from the fact that experimentation and research is fully integrated into the educational process. In fact, the university laboratory is regarded as one of the major innovations in the process of instruction in natural sciences.

However, to look at university research separately from the previous stages of the educational process is to look at the tail end only. For what happens at primary and secondary school is of the greatest importance to the eventual supply of scientists and the strength of the research establishment. And whereas it may be argued further that there is an "organic connection" between the various types of educational institutions, a case can be made out for drawing the

1) GUNN, Lewis A.: "Organising for science in Britain: Some relevant questions", <u>Minerva</u>, vol. V, no. 2, Winter 1967, p. 168.

boundary of scientific policy to include the primary school.

(b) Link with application

The second association is that between research and the eventual implementation of its findings. It may be claimed that to be effective (in a social sense), research must be carefully keyed to the needs it is intended to fulfill. It must move with the pace of industrial and military development and react sensitively to the changing conditions and requirements of society, (e.g. in assisting in the control of pollution and congestion of economic centres). There should exist therefore, a coherent view of the chain of events leading from scientific discovery to eventual application of its findings. This places the boundary of scientific policy beyond the stage in which its findings are applied.

(c) Unified nature of scientific activities

On the one hand therefore, arguments exist for considering education and research the subject of a unified policy. And on the other hand it may be argued that applied research is so part and parcel of the field of application itself, that it cannot be viewed as belonging to a different social sphere distinguishable in terms of policy.

Cast in the above terms one may well reflect on the needs for a scientific policy per se. If the links between education and science, and science and application, are so strong, would it not be possible to regard science as a component of these other social sub-systems and a subject which could readily be governed in terms of their respective policies? This would, of course, imply an inner division of the whole body of science itself. Part of it (basic research) would fall within the educational sphere, and the other part (applied research and development) within the appropriate sphere of practical application.

But this is exactly what the scientific community isopposed to. As was pointed out above a basic need exists for a scientific policy to preserve the unique features of science. Furthermore, scientists are quick to point out that in itself the world of research constitutes a virtually indivisible whole. Advances in any one field are dependent upon, and influence, others. A common denominator exists in the "scientific approach", sets of personal values, and criteria for success, which are very different from any other sub-system in society.

For this reason scientists argue that the range of research activities falling between the educational process and the eventual implementation of research findings should be viewed as a continuous spectrum. Within this spectrum there are no inherent dividing lines suggested by the inner logic of the research process. Those that seem to exist[1] are artificially imposed from without. Any policy arrangement calling for the fragmentation of the research spectrum does not therefore reflect the realities of the situation.

It is argued then that scientific policy should take a holistic view of the continuum leading from education (including primary and secondary education) to research endeavour, to eventual application of research findings. In terms of this outlook scientific policy becomes extremely cumbersome and too unwieldy for practical use.

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1) GUNN, op. cit., p. 197.

Having expressed these misgivings about the practicability of formulating a viable scientific policy, we may now proceed with our attempt to construct a simple policy decision model. This will call for a significant narrowing down of the boundaries of scientific policy - an exercise which will be attempted in the next Section.

6.3 Reduction of the whole spectrum of policy issues in science to a number of key questions

A. Policy issues suggested in recent literature

We are here concerned with deriving a few key issues in scientific policy as the main ingredients of a (simple) decision making model. We have seen that the full true spectrum of policy issues is an entirely unmanageable political quantity. In order to proceed we must simplify - and acknowledge that we are now departing from the intricate detail of reality. It is hoped that a firmer grasp of the overall whole will compensate for this sacrifice.

Unfortunately there does not seem to exist a simplified, logically consistent and internationally accepted framework of scientific policy issues. Perhaps the best way to start therefore is to look at a framework of policy issues suggested by an accepted authority. For this we may turn to a very recent contribution by Spaey.

Two levels of choice are differentiated; first, the aims of scientific policy, and second, the choice of the means to achieve these aims. The following is a condensed frame of questions as suggested by the author.[1)]

(a) The aims of science policy

Three aims are differentiated -

(i) Defence, based on the desire for power, prestige or autonomy;

(ii) Economic, resulting from the need to ensure the development and therefore, competitiveness of industry and of agriculture - or more generally the desire to accelerate the economic development of the country;

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1) SPAEY, J.: "The problem of choice", in ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT: Problems of science policy, Paris, 1968 (OECD), p. 128.

(iii) Social, relating to health, culture, education or public services and which derive from a concern or desire for the progress or organization of society.

(b) Choice of the means to achieve aims

(i) Allocation of resources

(aa) First choice; what proportion of national resources should be devoted to science?

(bb) Second choice; what weight should be given to the three kinds of aims (political, economic, social-cultural)?

(cc) Third choice; how can respective weights to be given to fundamental research, to applied research and to development, be assessed (i.e. more generally, orientated and non-orientated research)?

(ii) The choice of research orientation

Within each of the three broad objectives of scientific policy alternative orientation may be decided upon. The following refer to research orientation in terms of the economic objective.

(aa) Major incentives to promote work on advanced systems.

(bb) Efforts in the key sectors of technological progress.

(cc) Initiatives aimed at future key sectors.

(dd) Large scale research activities for immediate or short term industrial application.

(ee) Development and applied research schemes in all capital goods sectors to pick up spin-off in (aa) to (dd).

(iii) The choice of research establishment

We may now re-examine the various choices differentiated by Spaey to see which of these constitute valid issues of scientific policy.

B. <u>Comment on suggested policy issues</u>

To quality as an element in a decision making model, a policy issue has to meet three requirements. First it must constitute a central rather than an incidental issue of scientific policy. In other words it must call for a decision which can be taken in its own right and which does not follo automatically from higher order decisions. Second, it must be cast in terms of variables with which policy makers are familiar or with which they can acquaint themselves. Third, the issues must be clearly and unambiguously formulated so that there is no uncertainty as to the nature of the decision being called for.

To what extent do the issues identified by Spaey meet these requirements?

(a) <u>The selection of goals</u>

In the framework of policy problems suggested by Spaey, three aims of scientific policy are suggested, namely, defence, economic and social. (See Sub-section 6.3 A (a).) For the purposes of scientifi policy this classification is unclear and inadequate in that the concept <u>social</u> is not explicit enough. Even though Spaey specifies the concept social as; health, culture and public service, we still find the concept <u>public service</u> not very expressive and the concept <u>culture</u> too unspecific. Also the concept <u>economic</u> is too vague.

A more suitable classification can be obtained if the goals for research are defined as those basic needs of the individual which have been accepted by society as worthy of pursuit by means of scientific investigation. We start, therefore, with the classification of individual needs. This gives rise to the following categories:

(a) Health - to live as long as the desire exists, and without bodily or mental inconvenience.

(b) Economic - to satisfy the basic needs of life and subsequently to gain leisure, and the opportunity to create and pursue wider interests, or to achieve social prestige through material ostentation, or the accumulation of wealth.

(c) Defence - to protect the desire for self-determination and to give effect to the "territorial imperative".[1)]

(d) Intellectual curiosity - to know more about things and about oneself, merely because of the primitive satisfaction which such knowledge gives. For society as a whole this may be seen as a cultural objective ("culture generále") or, in the case where it is closely integrated with the educational process, as an educational objective.

(While this classification is more useful for policy-making purposes than the classification suggested by Spaey, it should not be interpreted as reflecting the ultimate in human desire. It could, therefore, change with time. For instance, some very important basic human needs have been left out. The common human desire to know (for example by means of sense cognition) as opposed to belief, whether God exists, and other similar issues, may quite well one day constitute the central themes of scientific investigation - but only

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1) The basic animal need for a given territorial domain and which, it is suggested, constitutes part of the essential features of the human make-up. Taken from ARDREY, Robert: The territorial imperative, London, 1967 (Collins).

once the complexities of the physical world had been rendered comprehensible and once news of the meta-physical world is brought back from the outposts of human knowledge).

No doubt, future work will give us a better concept of what humanity really regards as true objectives. In the meantime the above, amended, list provides a convenient basis for scientific policy.

(b) Resources to be devoted to science

The second issue of scientific policy identified by Spaey concerns the proportion of national resources to be devoted to science. (See Sub-section 6.3 A (b) (i) (aa).) This is probably one of the first questions which policy-makers ask themselves when faced with the task of having to formulate the scientific policy for a given country.

However, the proportion of national resources which should be devoted to science is merely the sum of the scientific resources required to achieve certain specified social goals. In a sense, therefore, decisions concerning the sum follow automatically from the decisions concerning the individual parts.

Not that the total allocation is of no significance. It is, but it should be seen as a control variable used in an ex post capacity, i.e. as a restraint on the total allocation. It is not an issue involving its own ex ante decision.

(c) Relative weights to be attached to the various objectives

Within the framework suggested by Spaey (see Sub-section 6.3 A (b) (i) (bb)) this issue is concerned with apportioning the total allocation of funds for research and development among various research activities associated with the goals identified. However, as pointed out above, the true order of decision making is the other way around. It is taken with respect to individual goals, from which the total follows automatically. Even then the allocation of research funds to various social goals, depends on two things. First, the relative importance of the various social goals (without even considering the rôle of science), and second, the research production function for each goal, or in other words the ease with which it can be attained.

This issue becomes a valid issue of scientific policy if it is interpreted literally as the question of attaching weights to the various <u>social</u> objectives - without confusing the issue by considering it in terms of the amount of money to be devoted to the various associated <u>research</u> directions.

Strictly speaking the allocation of weights can be said to be derived from a supreme national objective function (as decided upon at the highest policy-making level) containing the whole array of national objectives, together with their respective weights. From this function a sub-function may be composed consisting of all those goals which are attainable (or at least partially attainable) by means of scientific research. This sub-set of goals together with their appropriate weights, may be termed the national objective function for science.

(d) <u>The relative weights to be attached to fundamental research, applied research and development</u>

The fourth issue raised by Spaey, concerns the respective weights to be given to fundamental research, applied research and development. (See Sub-section 6.3 A (b) (i) (cc).) We will not devote too much attention to this issue as it is becoming more and more apparent that it does not constitute a valid issue of scientific policy. It follows from previous decisions and is cast in terms which lack precise definition.

(e) Choice between research orientations

The fifth issue raised by Spaey, concerns the choice between research orientations, or in other words the particular field to be exploited in striving for a given social objective. (See Sub-section 6.3 A (b) (ii).) Spaey deals with one example, namely, the economic, to which we will also limit ourselves.

In the economic field science may be employed to generate economic benefits in the following main areas (of these Spaey only deals with (iii)):

(i) To provide a scientific base for regulating the environment in order to maintain it as an unpolluted and uncongested space for industrial operations.

(ii) To support national action aimed at across-the-board, (irrespective of sector of production) increases in the productivity of factors of production.

(iii) To directly promote certain sectors. Here various alternatives exist, as identified by Spaey (and mentioned earlier) and which will not be repeated here.

This issue also meets with all the requirements for a valid issue of scientific policy. It can be clearly formulated, and decisions thereon are both taken in their own right and in terms of variables which are familiar and in practical every day use. It may be pointed out that the selection of the particular orientation will closely follow the dictates of economic policy.

(f) Choice of research establishments

The final issue identified by Spaey is the choice between research establishments. (See Sub-section 6.3 A (b) (iii).) If the key question lies in selecting the correct type of research establishment to create in order to give effect to a research programme already decided upon this is very much of an organizational question and not a valid issue of scientific policy.

However, if the issue is seen as choosing between research establishments merely as a convenient method for distinguishing between the goals they represent, the issue approaches the nature of an essential issue.

C. Concluding remarks

We may conclude by observing that the choice of goals and the relative weights attached to each are the most central issues in scientific policy-making.

The question of how much should be devoted to science is also of importance - but merely in the sense that it is concerned with establishing an upper limit and not in the sense that it is concerned with choosing the correct level - this follows from other decisions. Also, under certain circumstances, the choice of research establishments, may be seen as a valid question of scientific policy.

On the other hand, the question as to the weights to be given to basic research, applied research and development cannot be regarded as a central issue in scientific policy-making, and neither can the question concerning the amount of research money to be allocated to various social objectives. Both these questions are automatically resolved by higher order decisions.

When the valid issues of scientific policy are formulated in this way it seems that the central problem of scientific policy-making reduces to a problem of correctly allocating scientific resources to achieve social objectives weighted in a particular manner, and subject to a restraint on the resources available. This is strongly suggestive of a linear programming approach. The possibility of using such an approach is discussed in the next Section.

6.4 A model for resolving the issues of scientific policy

A. General features

To continue in our attempt to find a model for incorporating economic considerations into scientific policy-making at the national level, we may now examine the possible use of linear programming procedures to construct a decision making model involving the valid issues of scientific policy.[1)]

The programming technique is applied to three sets of data, viz:

(i) An objective function, expressing the various objectives of scientific policy in quantitative terms, as well as their relative weights in terms of social preference.

(ii) A set of production functions relating various levels of achievement of scientific objectives to the level of resource input.

(iii) A set of constraints on the scientific inputs available and which, for example, can either be in terms of the budgeting constraints, or manpower constraints.

According to linear programming procedures resources are allocated in a given manner which will ensure the maximization of the objective function up to the point that any given constraint becomes operative. The model then specifies the total resource allocation and its breakdown into various types of inputs which ensure the optimum achievement of the objectives formulated and which take into account any limitations on inputs.

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1) This approach is based on a procedure outlined in: MAASS, Arthur, HUFSCHMIDT, Maynard M., DORFMAN, Robert, THOMAS, Harold A., MARGLIN, Stephen A. and FAIR, Gordon Maskew: Design of water resource system, Cambridge Massachusetts, 1962 (Harvard University Press).

We may now investigate the various parts of the model more closely and reflect on its potential use in the field of scientific policy-making. In the course of this discussion the part which economic criteria play in the decision-making process will emerge clearly.

B. The formulation of the objective function

In section 6.3 it was pointed out that science has four objectives, namely:

(a) Contributing to economic aims.

(b) Contributing to military strength.

(c) Contributing towards health.

(d) "Culture generále".

The first requirement of the decision-making model is that each of these objectives have to be formulated quantitatively. In some cases this is easier than others. Take (a) for example as opposed to (b). Economic objectives may be expressed quite readily in percentage points of growth, a given measure of income distribution, the rate of employment, or other similar criteria. The military objective is a little more difficult to formulate in aggregate terms although it is not impossible. For instance, a probability estimate representing the likelihood of withstanding certain specified attacks could quite well serve as an estimate of military potential. However, to express the contribution to "culture generále" in quantitative terms appears to present very serious problems.

This does not disqualify the model however, as a provision may be built into the system for entrenching a minimum amount of resources to be allocated to uncommitted research (i.e. "culture generále"). Nevertheless it would be preferable to find some quantitative measure if at all possible.

In practice it will also be found that the four generalized objectives of science are too vaguely formulated to reflect the realities of policy-decisions. Turning again to (a) and (this time) to (c) the following, not always mutually consistent, sub-parts of the generalized objectives may be identified. In the case of theeconomic objective we may specify further:[1)]

(i) Economic growth, reflected in a long term increase in aggregate consumption levels.

(ii) Stability, which implies the maintenance of a non-fluctuating economic system and avoiding inflation.

(iii) A desired regional pattern of development which is of a more preferable nature than normal regional imbalance.

(iv) A desired pattern of income distribution which will be of a more equitable type than the extremely skew income distributions frequently encountered.

In the case of the health objective this can either be

(i) The maintenance of a pure and healthy environment.

(ii) Preventive measures against health hazards (on a community basis).

(iii) Remedial and corrective measures against unhealthy conditions (individuals).

As in the case of the various sub-parts of the general economic objective, so also these sub-parts of the general health objective are not always mutually consistent.

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1) See especially MARGLIN, Stephen: Public investment criteria, London, 1967 (George Allen and Unwin Ltd.), pp. 19 - 26.

The second requirement for constructing an objective function, is to express the relative social preference of each of the objectives quantitatively. This may be done by evaluating the various objectives in terms of each other. For instance, if four units of advance in military status is regarded as equal to one unit of advance in the economic field, the objective function could be formulated:

$$\text{maximise} \left\{ 4 \text{ (economic objective)} + 1 \text{ (military objective)} \right\}$$

The general form of the total objective function is as follows:

$$\begin{aligned} \text{maximise} \Big\{ & a\,(E_1) + b\,(E_2) + c\,(E_3) + \ldots\ldots. \\ & + l\,(H_1) + m\,(H_2) + \ldots. + p\,(M_1) + q\,(M_2) + \ldots\ldots \\ & + u\,(C_1) + v\,(C_2) + \ldots\ldots \Big\} \end{aligned}$$

Where:

E_1, E_2, E_3, etc.	=	various economic objectives,
H_1, H_2, etc.	=	various health objectives,
M_1, M_2, etc.	=	various military objectives,
C_1, C_2, etc.	=	various "cultural" objectives,
a, b, c	=	respective weights reflecting relative social preference attached to these objectives.

C. <u>The formulation of production functions</u>

A production function is a formal expression relating various levels of output achievement to given levels of input. A research production function therefore relates various levels of achievement in scientific objectives to given levels of scientific input.

The formulation thereof is the most difficult part (in an intellectual sense) of the present model. (In a political sense the formulation of the objective function is probably the most difficult part). Not only does the production function have to accommodate the exceptionally unique features of the scientific process, but it has to "fit in" with the requirements of the decision making procedure.

The features which have to be accommodated are; inter alia,[1)]

"(1) The absence of material production. The results of research units are new knowledge, technical solutions, etc. The basic product of science is information.

(2) Unpredictability or partial predictability of the results of research units.

(3) Lack of precise criteria for measuring the results of research.

(4) Lack of serial production - each product of research has its own individual traits.

(5) The multiplicity and variety of resources used and the high significance of some, as for example the resource of scientific information".

Figures I and II are schematic presentations of research production functions reflecting some of the unique features of the research process.

In Figure I research output, as measured on the y-axis, is expressed in terms of units of knowledge. Various levels of research input may be thought of as producing a family of output curves. Two members of such a family are shown. The graphs of the normal distribution which intersect the output curve at various points, reflect the stochastic nature of the research production function. Each graph represents schematically the

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1) KULESHOV, V.V.: "Problems of internal organization of scientific institutions," in: LAKTIN, G.A. (editor): Problems of economics and organization of research work (in Russian), 1967, Novosibirsk: Siberian section of Nauka. Quoted in: DEDIJER, Stevan, "Models of science for science policy", Advancement of science, June, 1968, p. 502.

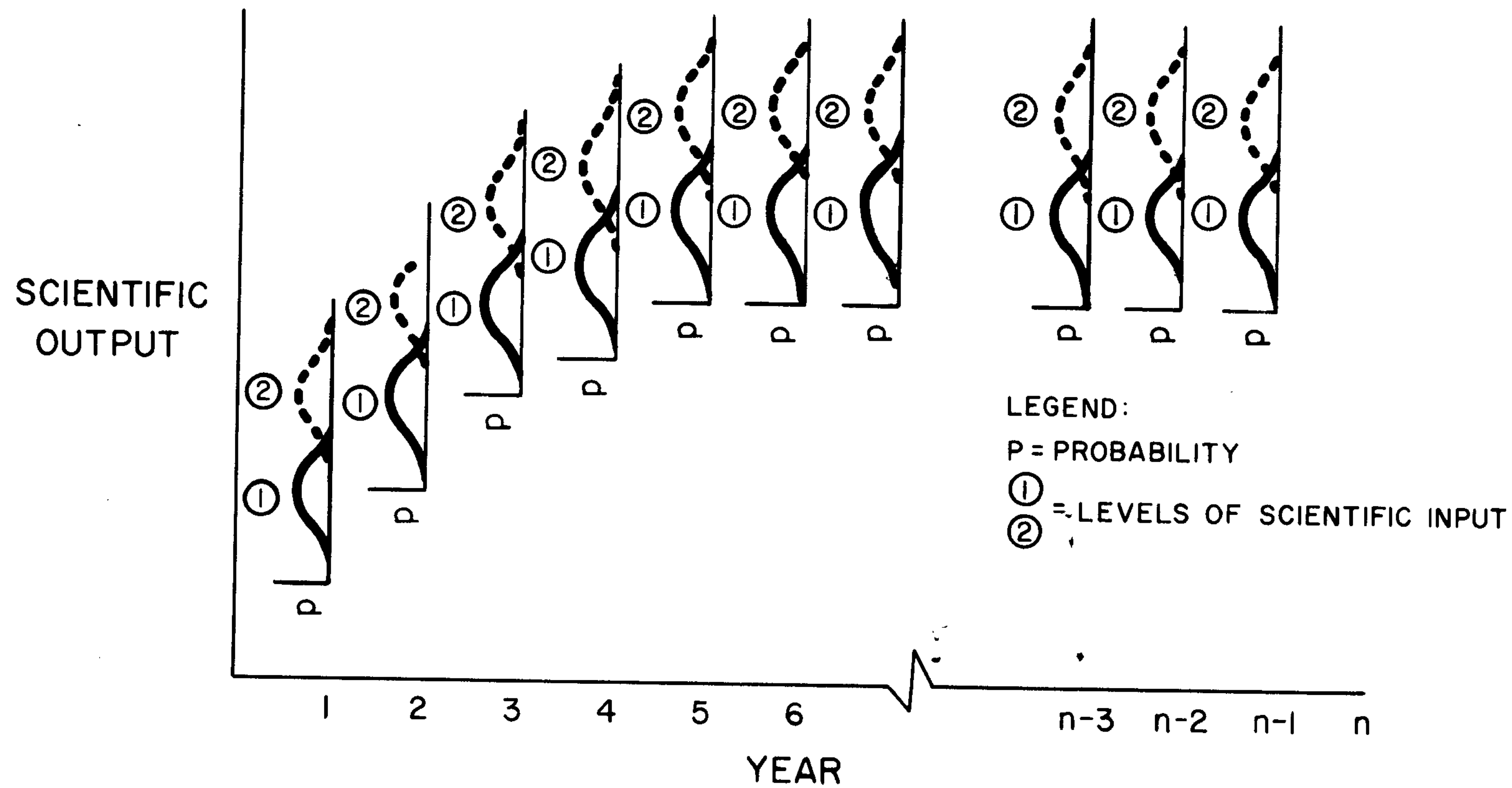

FIGURE I

Relationship between scientific output and intensity of scientific input

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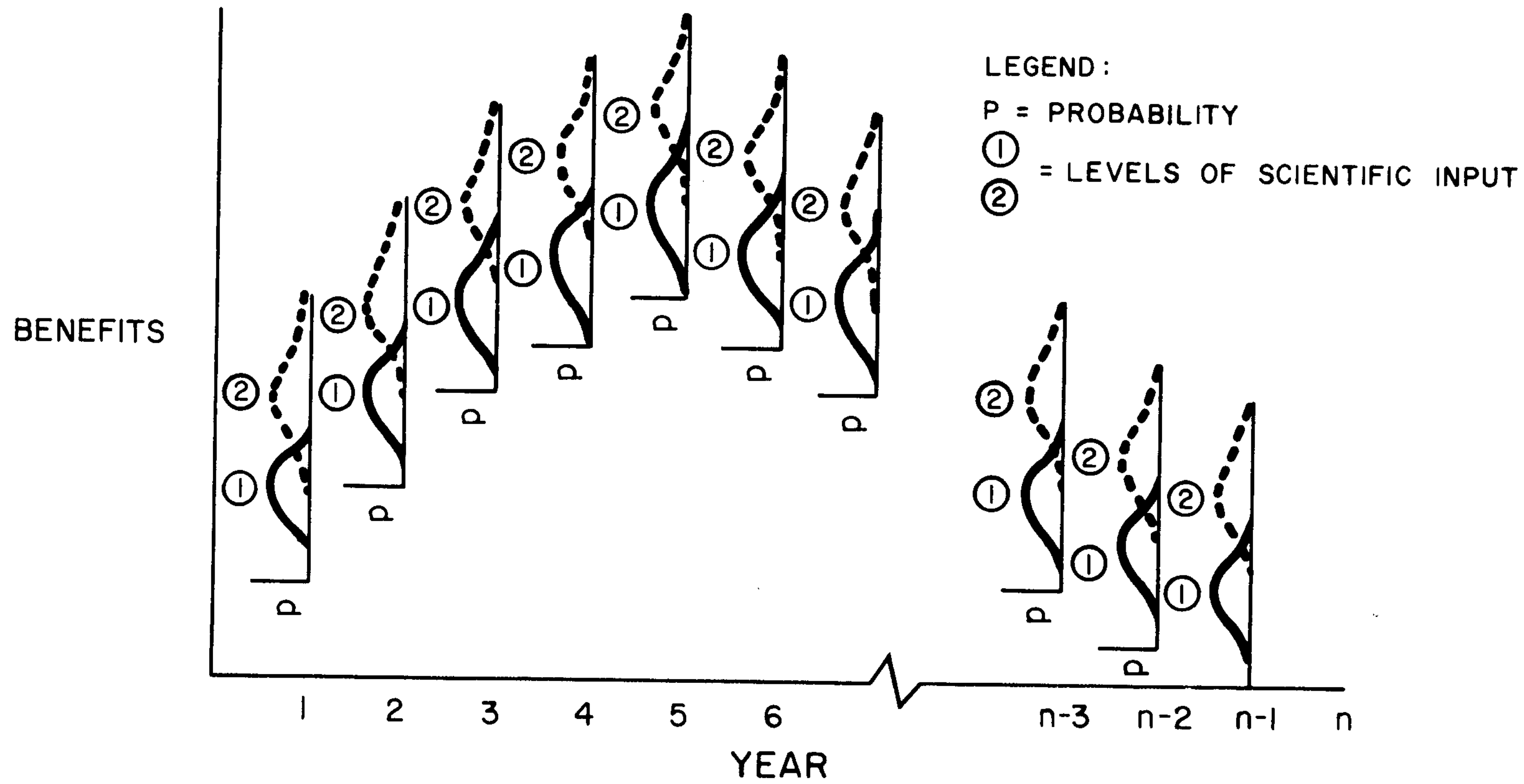

FIGURE II

Relationship between economic benefits and intensity of scientific input

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probability that the level of output indicated will be attained, given the level of input indicated. The growth and tapering off stages of the curve indicate that the fund of knowledge produced by the research project accumulates up to the point that the research project is terminated. Thereafter the results are available ad infinitum.

In Figure II the same general features are shown. Here however, output is expressed in terms of the value of the knowledge generated. The different behaviour of the curve when compared to the curve in Figure I stems from the fact that the economic value of research findings become eroded through time as the findings lose their relevance. Consequently the output of a given scientific research project does not have a value ad infinitum but experiences a steady decrease over time.

Not represented in Figures I and II is the procedure for discounting future benefits (or levels of achievement) to a present value. This introduces serious qualifications because the long time lag renders the discounting process extremely sensitive to the level of interest rate used.

All of these features have to be incorporated into a mathematical formulation of the production function.

As for the requirement that the variables in terms of which research input is measured must be the same as the control variables used by policy makers, this implies that the form of the production function will also depend to a very large extent on the degree of detail with which policy makers formulate their allocation decisions. If these decisions are made in terms of research institutions the production functions will be the production functions of various institutions. If the decisions are made in terms of various projects (which is highly unlikely) the production functions will be those pertaining to the various projects; and so on. The degree of detail in terms of which policy decisions are made influence not only the nature of the production functionsused in the model but also the number.

In practice a production function will be a particular version of the general form:

$$(E_1, E_2, E_3, \ldots H_{.}, H_2, \ldots M_1, M_2, \ldots C_1, C_2, \ldots)$$
$$= f_i \quad (x_i \; y_i).$$

Where :

E_1, E_2, E_3 H_1, H_2, M_1, M_2, C_1, C_2,	)	All have the same meaning as in Sub-section 6.4 B
x_i	=	x_1, x_2, ... x_n, represents current expenditure, i.e. expenditure on salaries of research workers plus stores, plus overhead, but excluding expenditure on plant and equipment, for various production functions.
y_i	=	y_1, y_2, ... y_n, represents expenditure on plant and equipment for various production functions.
i = 1, 2, ... n		represent the number of institutions (research teams, projects, research direction etc.) for which separate production functions are required.

D. <u>The formulation of constraints</u>

The rôle of constraints in the model is to place some sort of limitation on the allocation of scientific resources. Unless constraints are introduced, the model will indicate that the optimum allocation of scientific resources to research and development is infinite.

What constraints could exist in practice and how are these to be formulated?

(a) Manpower constraint

First there is a manpower constraint which exists by virtue of the fact that only a limited number of people in any country are capable of performing research.

This constraint may be formulated:

$$\sum_{k=1}^{s} x_k \leq CL$$

Where:

x_k = current expenditure on the kth research team in the country.

C = cost per research worker excluding equipment.

L = number of research workers available .

k = 1 ..... s, denoting various research teams.

(b) Budgeting constraint

Second, there may be a budgetary constraint which may be expressed either as percentage of gross domestic product or percentage of government expenditure.

This may be formulated:

$$\sum_{k=1}^{s} (x_k + y_k) \leq Q$$

Where: x_k = current expenditure on the kth research teams.

y_k = capital expenditure on the kth research team.

Q = amount which may be devoted to research and development.

(c) Quality requirement

Third, there may be introduced a quality requirement, which in the case of research aimed at economic objectives may be in the form of a benefit/cost ratio, (or, in the other cases, an effectiveness/cost ratio.) A constraint formulated as a benefit cost ratio for the kth research team may be expressed:

$$\frac{B}{\sum_{m=1}^{t} (x_{km} + y_{km})/(1+i)^m} \geq 2 \text{ (say)}$$

Where: B = total discounted future benefits from activities of the kth research team.

m = 1, 2, 3 .... t, i.e. periods over which research is conducted.

i = rate of interest.

E. Practical use of the model

In principle a model of this nature would have great practical value. Firstly, it would specify the amount of resources to be devoted to science in the country being studied, and also prescribe how much money should be channelled into each research unit or team (depending on the formulation of the production function).

Furthermore, it would indicate exactly how much of each objective will be obtained - giving policy makers the opportunity to reconsider whether the level achieved is adequate and whether they do not wish to alter the relative weighting of the various objectives.

Finally, the model would indicate which particular constraint is operative - again giving policy makers the opportunity for reconsidering the need for (or validity of) the constraint and whether it could not be relaxed somewhat in order to ensure a higher level of achievement of the objectives specified. Unfortunately, however, a number of very serious practical difficulties limit the effective use of this model.

First, the model is extremely limited in its scope and can only accommodate a small part of the whole spectrum of issues with which policy-makers concern themselves. For this reason it would provide marginal assistance only in the whole question of scientific policy-making.

Second, a very real problem exists in connection with the formulation of the relevant research production functions. These functions would be of a fairly advanced mathematical form and furthermore, require knowledge (about the nature of the scientific research process) of a type not freely available at present.

Third, the effective use of the model would depend to a very large extent on the ability of policy-makers to formulate quantitatively a social objective function for the nation, and on their ability to evaluate the findings of the model and to re-appraise their decisions. It is highly questionable whether such a level of sophistication will be achieved by the political process in the near future.

In view of all these limitations, we may very well ask whether we have gained anything from our attempts at constructing a decision making model for scientific policy issues. The answer is undoubtedly in the affirmative. For we have now observed, at least, that issues of scientific policy <u>may</u> be placed in a logical structure within which we can locate the position of economic objectives. We may not have found the source of the Nile, but we have charted much of the surrounding territory.

7. THE INTEGRATION OF SCIENTIFIC AND ECONOMIC PLANNING: SOME BASIC PERSPECTIVES

7.1 Introductory remarks

In the previous Chapter we concerned ourselves with questions of scientific policy making at the national level, and with the possibility of formally introducing economic considerations into this process. In this Chapter we turn to a more limited question on a lower level of decision making, namely: Can we develop a system of planning for science which can be integrated into the currently popular systems of economic planning?

The notion of integrating scientific and economic planning is, of course, not new. A number of writers have urged attempts in this direction[1] on the strength of the argument that the results of scientific research change the basic technological structure of an economy and thus eventually determine the relationship between economic inputs and outputs.[2] Other writers however, have expressed reservations about the integration of scientific and economic planning. So, for instance, Pavitt[3] maintains: "I am not sure that the simple exhortation 'Let's link our choices in research and development to our economic plans' is a viable one."

One of the major problems would seem to lie in the difference in the time dimensions between scientific and economic planning. Economic planning of the type undertaken by the Commisariat du Plan in France, the National Economic Development Council in Britain and the Department of Planning in South Africa, cover periods of no more than half a decade or so. Such a

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1) MESTHENE, Emmanuel G.: op. cit., p. 132.

2) Note for instance the recognition given to the long term effects of science by: MASSE, Pierre: "Les principes de la planification française", Weltwirtshaftliches Archiv, Band 92, Heft 1, 1964, p. 115.

3) PAVITT, Keith: "Some implications for government policy", in: ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT: Problems of science policy, Paris, 1968, (OECD), p. 87.

period would, however, be much too short for any sort of scientific planning. Scientific research, if successful in terms of its social objectives, would in most cases not have an impact in less than a decade after the decision was taken to pursue the given objective. If there is to be any integration of scientific and economic planning, the economic plan will have to be of a long term nature - say one to two decades.

Pavitt seems to express the same idea when he maintains: "It seems to me that in order to make these sorts of choices a country must have an industrial strategy. I am not sure that conventional methods of economic planning as at present conceived, enable such a strategy to be developed".[1)]

Ideally therefore we are looking for a new concept in economic planning, free from the limitations of present procedures. Unfortunately this has remained an elusive goal of which we have, at present, only vague and fleeting impressions.

These are best discussed in the light of present economic planning procedures. We may start therefore with a description of the conventional procedure for economic planning as presently practised in various Western countries. Within this general framework we will identify the rôle ascribed to science. Thereafter we will investigate certain variations of the said planning procedure to try and identify the conditions under which science becomes a significant force which has to be explicitly accounted for. Throughout the discussion the concept "planning" will be used in the context "indicative planning".

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1) Ibid., p. 87.

7.2 Present short term economic planning procedures and the rôle ascribed to science

A. Short term economic planning and input-output analysis

The basic technique of short term economic planning is the use of input-output tables to calculate the expected implications for the economy of an assumed overall rate of growth.

These input-output tables give details of the transactions between various sectors of the economy. The central core of an input-output table is a two dimensional table with equal numbers of rows and columns. All the sectors of the economy are then listed horizontally as well as vertically. The vertical listing refers to each sector in its capacity as a seller, while the horizontal listing refers to each sector in its capacity as a buyer. Added to this central core is an additional number of columns representing the purchases for consumption, capital formation, exports and imports (as a negative quantity); as well as an additional number of rows representing payment to factors of production and payments to government in the form of indirect taxation.

For each sector (row) one may differentiate therefore the sales to other sectors (columns) of the economy as well as to final demand (consisting of consumption, investments and exports).

Each column, on the other hand provides details of the purchases of a given sector from each other sector, as well as its purchases of productive services, i.e. labour,capital and enterprise, and finally payments to government.

The total of all payments to productive services (plus indirect taxes less subsidies) equals the gross domestic product at market prices and this total again equals the total of all sales destined for consumption, investments or exports (less imports).

If, in the case of a given sector, each purchase from another sector is expressed as a fraction of the total purchases of the first, a ratio is obtained of volume of inputs required to produce one volume of output of the sector under consideration. These fractions, or ratios, are called technical coefficients.

The nature of these technical coefficients are such that they are relatively stable over the short term (say five years), and this gives the input-output table its interesting predictive value. It may be shown namely that an input-output table can be constructed with two sets of data, viz (i) the technical coefficients of each sector, and (ii) the vector of final demand for the output of each sector.

As far as the planning procedure is concerned it is customary to estimate a demand structure for a point in time (usually) five years hence. This estimate is based on a certain "reasonable" growth rate for gross domestic product. This demand structure is then superimposed upon a given set of input-output coefficients and the complete implied set of intersectoral transactions of the economy finally determined.

At this stage the full range of implied transactions are checked to identify any possible bottlenecks. These could occur in a number of areas, of which labour supplies,[1] balance of payments disequilibrium and natural resource supplies, are the most common. If bottlenecks occur, a lower overall growth rate is used in the calculation and the procedure repeated until a growth rate is found which can be readily maintained, free of bottlenecks, by the entire economy.

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1) Allowance is usually made for a steady increase in output per labourer over the planning period. This reflects the increased use of capital as well as a measure of increased productivity.

This growth rate is then designated the "target" growth rate and its full implications accepted as guidelines for action by the government and business sectors.

On the basis therefore of a projected vector of future demand, a given set of technical coefficients, and given restraints which may operate in the economy, it is possible to indicate with a certain measure of logical consistency, what the economy could look like (say) five years hence.

B. The rôle ascribed to science

In the planning procedure outlined above,[1)] a neutral rôle is usually ascribed to science. This may be deduced from the fact that over the planning period technology is assumed constant and not subject to radical change.[2)] Both the technical coefficients and the income elasticities of demand for various categories of goods are treated as relatively stable.

Allowance would, of course, be made in the table for government expenditure on research and development as part of total government expenditure, and it would even be possible to group all expenditure on research and development in a special category within the table. But, as far as can be determined, no country allows for the effects of this research on the technical relations within the economy by systematically varying the technical coefficients.

The need for introducing changing technical coefficients would only seem to arise therefore when the planning period is significantly lengthened to extend over, for example, two to three decades. We may with benefit

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1) Based on descriptions in: DENTON, Geoffrey, FORSYTH, Murray and MACLENNAN, Malcolm: Economic planning and policies in Britain, France and Germany, London, 1968 (George Allen and Unwin), and: MILLIKAN, Max F. (Editor): National economic planning, New York, 1967 (National Bureau of Economic Research, and distributed by Columbia University Press).

2) A measure of change is allowed for in the steady increase of output per labourer.

therefore examine the rôle ascribed to science and changing technology in long term economic planning.

7.3 Long term economic planning and changing technology

While the principles and procedures of long term economic planning (the term planning again being used here in the context of indicative planning) are still in their infancy, isolated examples exist of long term comprehensive economic forecasts.[1] And as these forecasts will eventually form the basis of long term planning it is useful to examine the manner in which they account for technological change.

As Fourastie[2] has pointed out, the impact of changing technology should be sought in changing supply conditions on the one hand and changing demand conditions on the other. Whereas we may expect a more readily identifiable link between changing technology and supply conditions, than between changing technology and demand conditions, we will concentrate on the former.

In long term economic forecasting two complementary methods have been suggested for forecasting changing supply conditions, i.e. for predicting future values of technical coefficients. These are, firstly, extrapolation of past trends in technical coefficients, and secondly, technological forecasting. Each of these may now be discussed.

A. Extrapolation of past trends in technical coefficients

If technical coefficients in two input-output tables for a given economy are calculated at different points in time (separated by a reasonably long period such as a decade) it will be noted that these coefficients exhibit a change which seems to follow a particular pattern. In a recent study (one of the first of its kind), Anne Carter[3] compared the input-output

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1) See for instance: ALMON, Clopper (Jr.): The American economy in 1975 - an inter-industry forecast, New York, 1966 (Harper and Row).

2) FOURASTIE, Jean: Moderne techniek en economische ontwikkeling, Utrecht, 1965 (Aula Boeken).

3) CARTER, Anne P.,: "The economics of technological change", Scientific American, vol. 214, no. 4, April, 1966.

tables for the United States for the years 1947 and 1958[1] and came to the conclusion that two marked trends were discernible in the value of technical coefficients.

On the one hand there seemed to occur a relative increase in non-material inputs accompanied by a relative decrease in material inputs, while on the other hand there seemed to occur greater diversification in inter-sectoral purchases.

(a) Increase in non-material inputs

The "non-material" or "general" inputs which show relatively rapid growth include; "energy, communications, trade, packaging, maintenance, construction, real estate, finance, insurance, and other business services, printing and publishing, and business machines and their related information technologies".[2] In other words this category embraces those inputs used in all, or almost all, sectors of the economy, as opposed to those inputs which are of specific importance to a few sectors only and which usually consist of materials and semi-finished goods.

This trend is illustrated in Figure III which is based on an illustration in the publication by Carter.[3] It shows the changing share of three classes of input, i.e. general inputs, material inputs and chemical inputs in the total input requirements for various specified products.

These figures refer to the American economy and relate to the two years 1947 and 1958.

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1) In a more recent article the analysis is extended to cover 1962 as well. CARTER, Anne P.: "Changes in the structure of the American economy 1947 to 1958 and 1962, Review of Economics and Statistics, vol. XLIX no. 2, May, 1967, pp. 209 - 224.

2) CARTER, Anne P.: "The economics of technological change", op.cit., p. 27.

3) Ibid., p. 28.

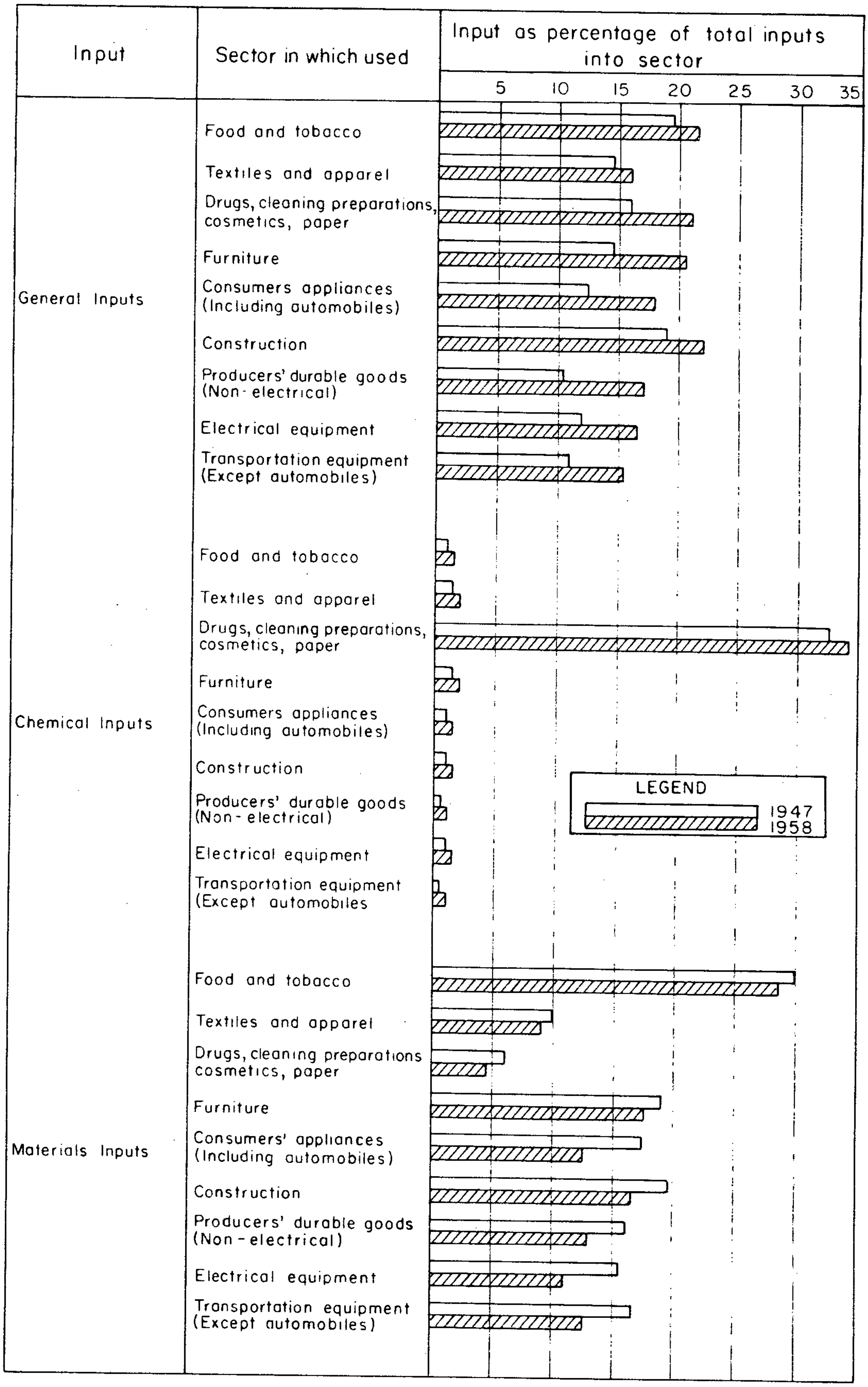

FIGURE III

Percentage share of three types of input in total input requirements of various sectors

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From Figure III it can be seen that the general inputs contribute proportionally more in 1958 than in 1947 to the output of the products specified. The same pattern can be observed for chemical inputs, while the reverse trend can be seen for material inputs.

(b) Diversification in inter-sectoral purchases

Accompanying the relative decline in material inputs, Carter differentiates a second trend. "The classical dominance of single kinds of material - metal, stone, clay and glass, wood, natural fibres, rubber, leather, plastics, and so on - in each kind of production has given way by 1958 to increasing diversification of the bill of materials consumed by each industry."[1)]

This second trend is illustrated in Figure IV which shows the requirements which two chosen sectors, namely textiles and apparel and construction, have for various specified inputs. This figure too is based on an illustration in the article by Carter.[2)]

Figure IV suggests that there is a certain tendency for inputs to "level out" - although this cannot as yet be formulated as a general rule because of the obvious exceptions in the case of the first, second, third and sixth material in the sector textiles and apparel. Nevertheless this figure shows clearly that in the case of the textiles and apparel sector, natural fibres such as wool and cotton are replaced by synthetics, while in the case of the construction sector, iron and steel is replaced to an increasing extent by cement and concete.

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1) Ibid., p. 27.

2) Ibid., p. 29.

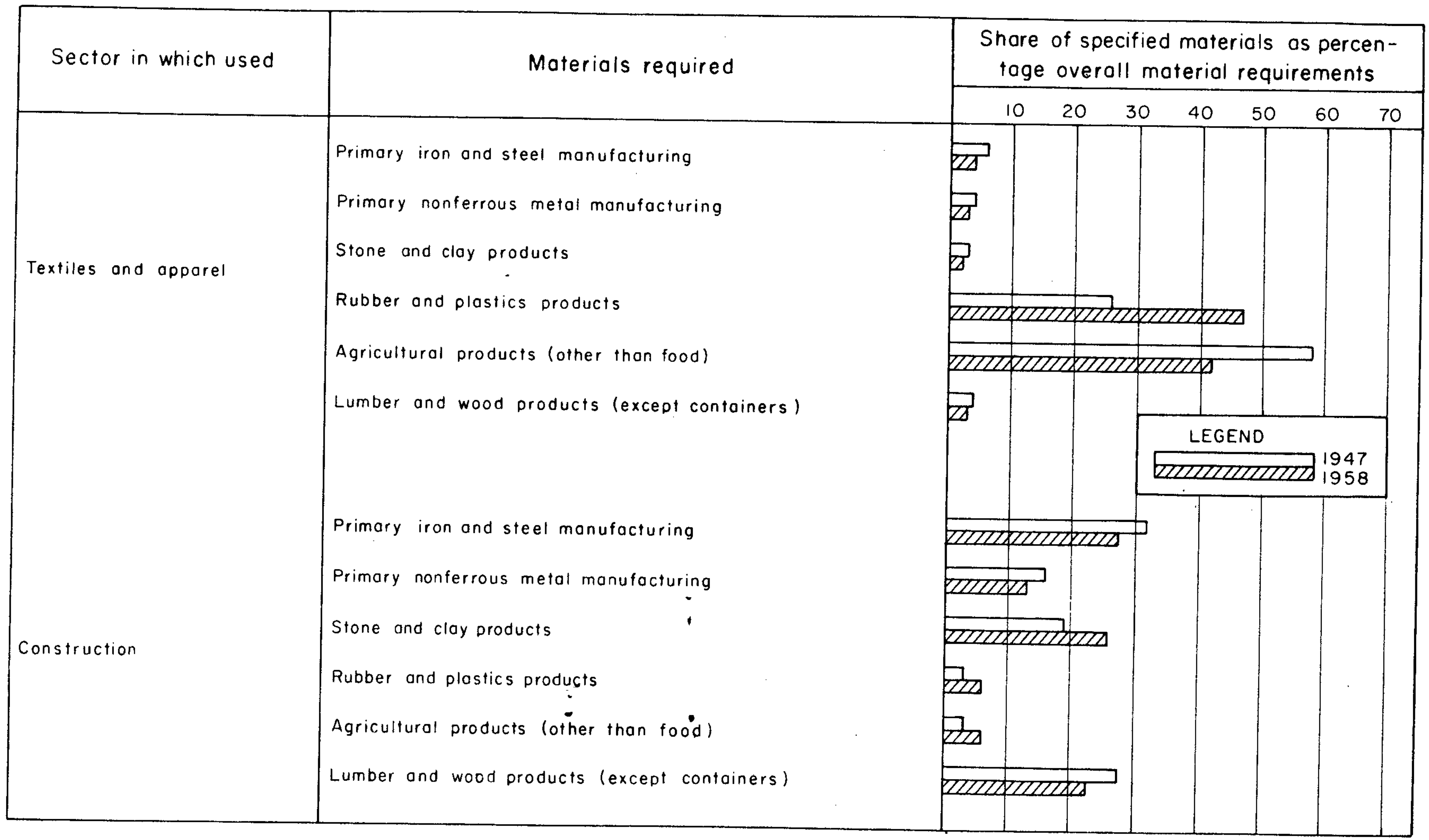

FIGURE IV

Share of specified materials as percentage of overall material requirements in two sectors

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B. Technological forecasting

Apart from the empirical approach discussed above and involving an extrapolation of past trends, there is another approach which delves a little deeper into the underlying forces of change. This approach is known as technological forecasting, and in spite of its promise for economic analyses economists do not yet seem to have generally accepted it as being of relevance to their methods and techniques.

A technological forecast is no more than disciplined conjecture about the speed at which the next level of technical achievement will be attained. At first glance, this conjecture would seem to be entirely without any systematic foundation. But this is not true.

In the first place, there seem to exist a number of fixed long term trends reflecting man's increasing technical capability. And in the second place, it would appear that the successive stages of development within these trends follow a given pattern.

(a) Long term trends

As far as the long term trend in man's technical capability are concerned, we may refer here to Bright who has identified the following:[1)]

(i) Increased transportation capability which involves inter alia, mastery of greater distances in less time and/or cost, as well as movement and operations in new media such as space, under-seas, and arctic areas.

(ii) Increased mastery of energy, which will be exhibited in the following ways: far greater magnitudes and intensities of power available; energy handled in more minute quantities,

1) BRIGHT, James R.: "Opportunity and threat in technological change", Harvard Business Review, vol. 41, no.6, December, 1963, pp. 76 - 86.

and controlled with increased precision; power generated and transformed by new sources and devices; significant advances in energy storage; new techniques for large scale transportation of energy and fuels.

(iii) Increased ability to extend and control the life of animate and inanimate things, which will be reflected by; alteration of living things; longer life for perishable foods and other organic products and items; reduced deterioration in physical goods.

(iv) Increased ability to alter the characteristics of materials as reflected by; new properties for old materials; synthetic materials; combinations of materials to provide unique characteristics.

(v) Extension of man's sensory capabilities, such as; vision; hearing; touch; power of discrimination - visual, olfactory, aural and so on; memory (preservation of visual and aural impressions.)

(vi) The growing mechanization of physical activities, especially in the fields of; production; communications and control; distribution; extraction industries and construction.

(vii) Growing mechanization of intellectual processes as evidenced by; collection of long intricate machinery actions; information processing; problem solving.

These then reflect the various broad areas of advance in human technical ability. An example of a steady increase in technical achievement is provided in Figure V where the growth in illumination

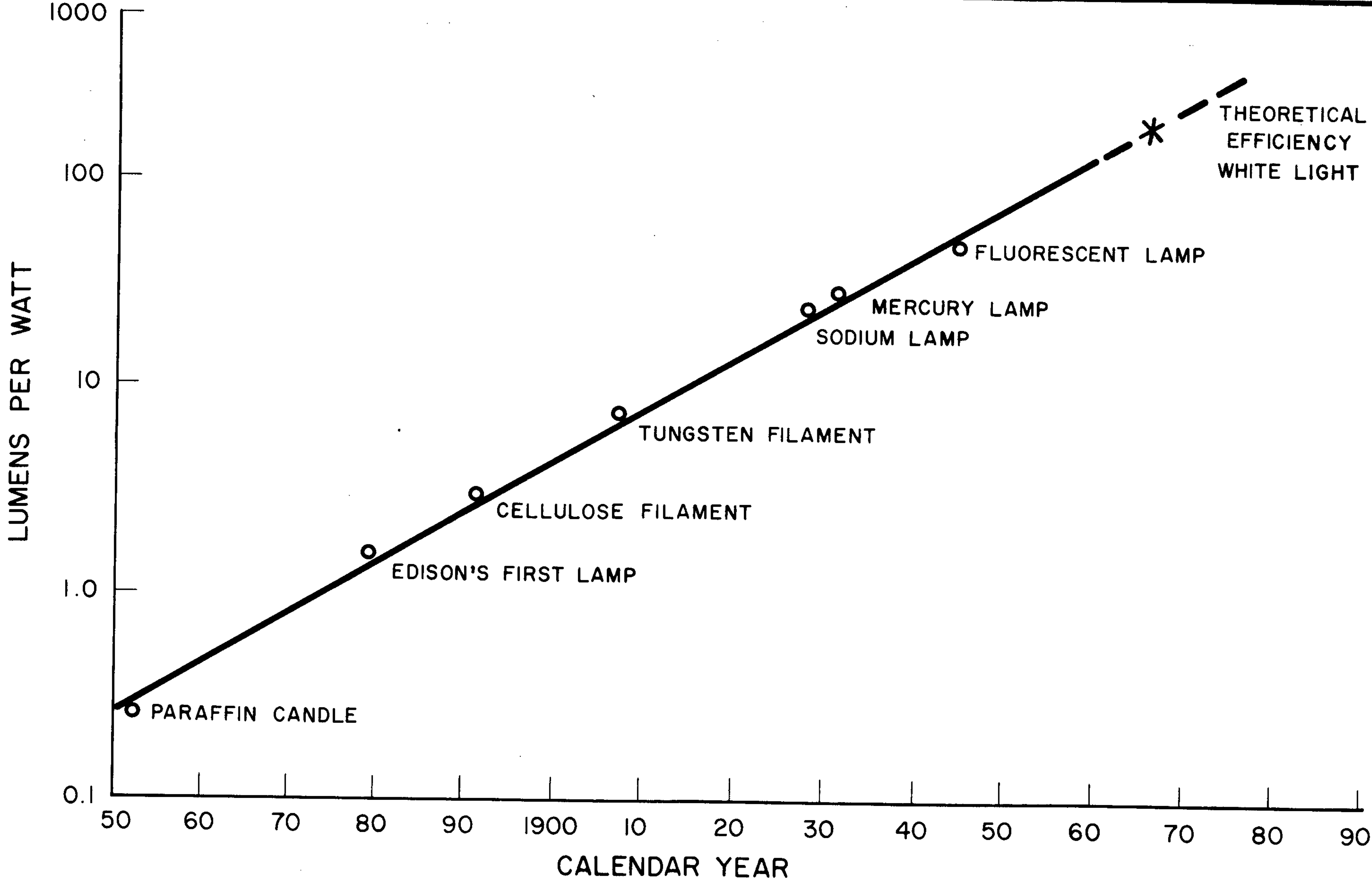

FIGURE V

Growth in technology of illumination

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technology is represented.[1]

However, to reduce these general technological trends to quantities which could be used in predicting technical coefficients in an input-output table, it is necessary to proceed from these broad areas to individual "stages" or "means" of advance. In the case of trend (ii) mentioned above, and in particular with reference to the item "power generated by new sources and devices", the following may be suggested: nuclear reactors, fuel cells, solar cells, magnetohydrodynamics, thermoionics, jet engines, stationary power plants.[2] Other broad areas may be similarly further specified.

(b) Individual developments

Fortunately, as stated above, the successive stages of development within these trends seem to follow a given pattern. This may be illustrated with reference to Figure VI where two typical S-curves are shown representing successive stages in illumination technology.

In his encyclopaedic review of the field of technological forecasting, Jantsch has attempted to determine the typical time pattern of technological developments.[4] A number of functions are found, among which the wellknown S-curve in statistics. Two examples of the use of the S-curve are given by Jantsch and are represented in Figures VII and VIII. Figure VII shows the relative effectiveness of various forms of transport and their improvement over time.[5]

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1) This figure is taken from: GODINO, Rodger: Planning for long term busines development in South Africa, Cape Town, July 1966, Seminar on long term planning, (National Development and Management Foundation of South Africa, Cape Western Region) (Mimeographed.) Graph B.

2) BRIGHT, op. cit., p. 79.

3) GODINO, Rodger : op. cit., Graph C.

4) JANTSCH, Erich: Technological forecasting in perspective, Paris, 1967. (Organisation for Economic Co-operation and Development).

5) Ibid., p. 161

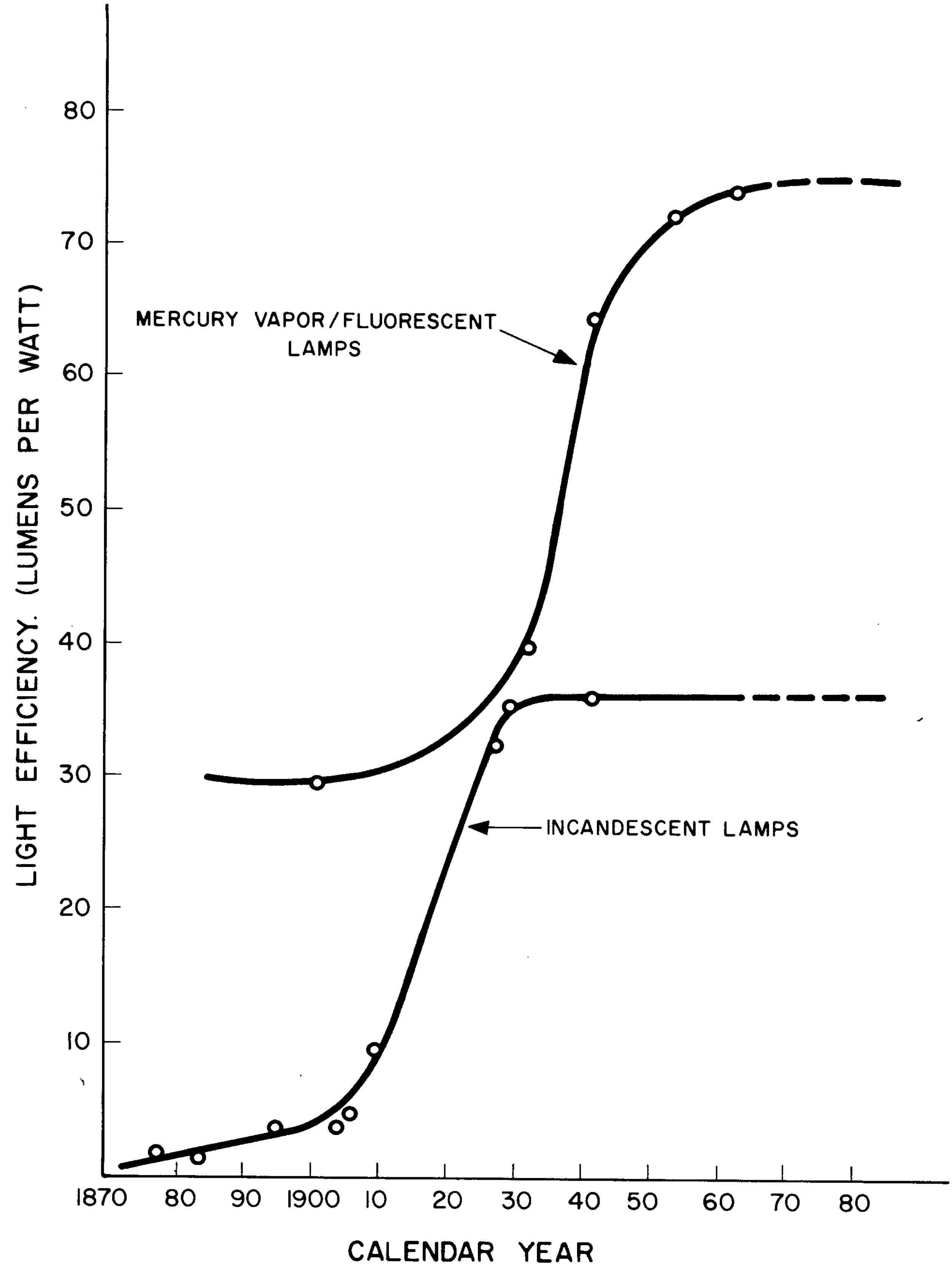

FIGURE VI

Two S-curves representing successive stages of development in technology of illumination

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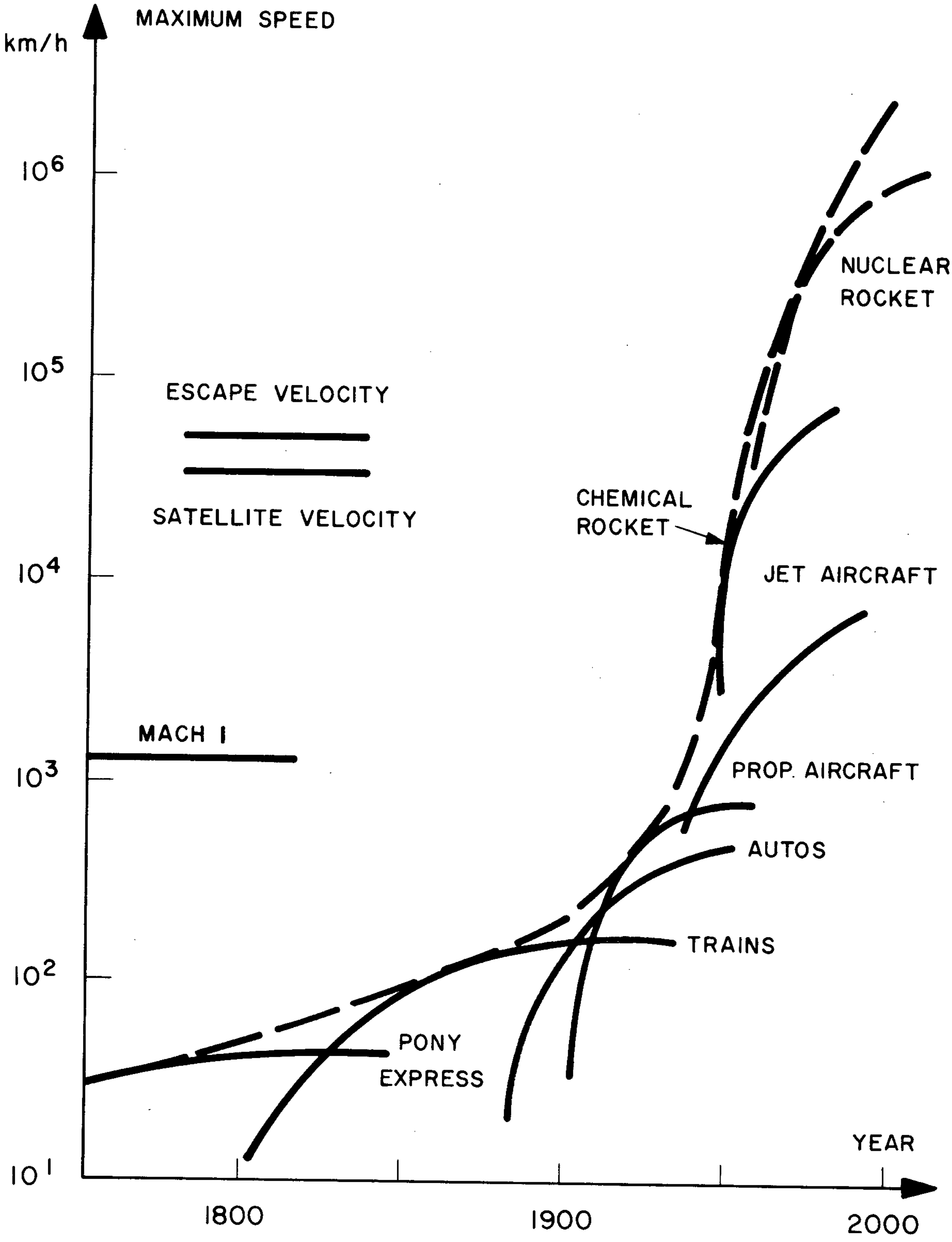

FIGURE VII

Successive S-curves representing stages of advance in transport technologies

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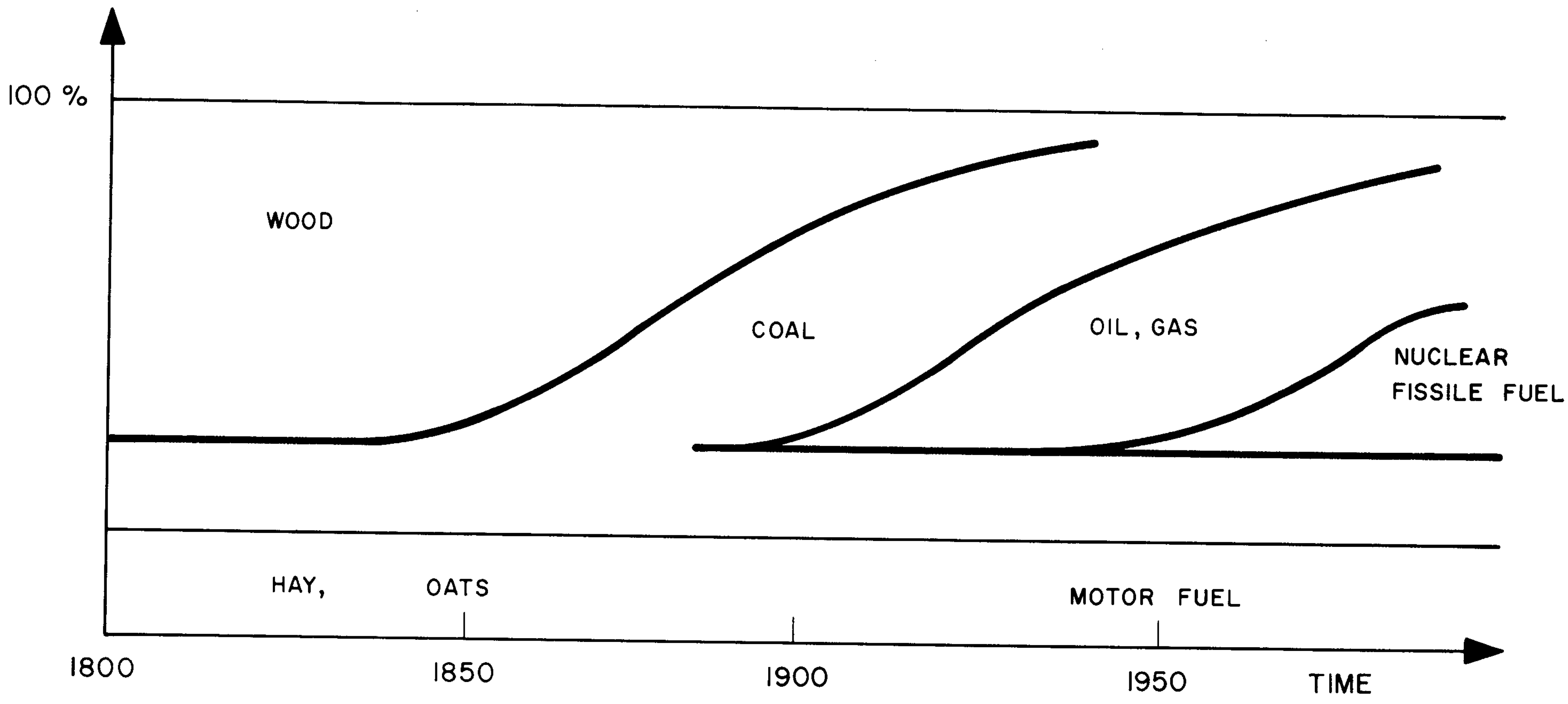

FIGURE VIII

Relative S-curves representing stages of advance in fuel technology

RG4-3129

Figure VIII incorporates a method which is probably more relevant to the purpose in hand and shows the trends in relative shares within the total consumption of fuels.[1)]

It is noted that with time the relative share of various types of fuels in the total pattern changes in a regular and systematic way.

In aggregate economic terms such a switch from one technology to another would be reflected in a change in the pattern of inter-sectoral purchases, and consequently a change in technical coefficients. It follows therefore that technological forecasting has an important rôle to play in the estimation of future trends in technical coefficients.

In concluding this discussion, one final feature of technological forecasting should be stressed, and that is that the methodology of this field consists of an own unique system and set of techniques and that little, if any, reliance is placed on the anticipation of individual specified scientific discoveries.

C. Other considerations in predicting technical coefficients

It has to be emphasized however, that all changes in technical coefficients do not stem from technological advance. Numerous factors may be responsible. As Morgenstern points out: "Unfortunately input-output coefficients are not truly technical data; they are obtained from operating upon value figures of sales and purchases. These are, however, at least as much influenced by price variations, monetary policy, inflation, etc. as by the progress of technology, scales of production operations, etc."[2)]

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1) Ibid., p. 167.

2) MORGENSTERN, Oskar: Foreword to the book by:
HATANAKA, Michio: The workability of input-output analysis, 1960, Ludwigshaven am Rhein (Fachverlag für Wirtschaftstheorie und Ökonometrie), p. iii.

So for instance Almon[1)] discusses the effects of changes in product mix on technical coefficients. The influence of this factor: ... "hinges on the fact that certain parts of some heterogeneous sectors are expected to grow faster than other parts of the same sector. When coupled with differences in the input coefficients of the components of a sector, these differences in the growth rate of the components produce apparent changes in coefficients, though no technological change is involved".

This specific type of adjustment is required therefore when the degree of aggregation is such as to include within a given sector radically different branches of industry. It involves the determination of the share of the various branches of industry within a given sector and the expected changes in these shares. From this it is possible to weight the various parts constituting the overall coefficient and to adjust these weights in terms of the different growth forces of the branches of industry within the sector.

However, for the purposes of the present exercise in which we are positively seeking ways in which to identify the impact of technology on input-output relations, these complicating factors are ignored.

D. <u>Forecast of the demand vector</u>

In the above discussion we have concentrated on changes in supply conditions. A long term economic forecast would of course, also have to take account of changes in demand conditions. And while we are not primarily concerned with these they are briefly discussed here for the sake of perspective.

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1) ALMON: op. cit., p. 114.

As far as the demand vector is concerned, this is broken down into three major components, namely:

(i) A schedule of domestic consumption demand;

(ii) A schedule of domestic capital formation;

(iii) A schedule of exports.

(a) Predicting the domestic consumption pattern

The long term prediction of domestic consumption patterns follows in principle the same methodology as for the prediction of consumption patterns for the (normal) short term (say five years) planning period Two guidelines may be used:

(i) Past trends in consumption patterns in the given country which help determine the income elasticity of demand for various consumption categories - in other words income elasticities of demand based on inter-temporal comparisons.

(ii) Cross section comparisons of consumption pattern in countries at different stages of economic development.

(b) Predicting capital formation

Whereas the gross domestic capital formation at a future date may be calculated with the aid of the incremental capital-output ratio (determined on the basis of past experience) the breakdown of the total amount into various classes of capital should take account of certain long term trends. Kuznets, for example, stresses two:

(i) The share of fixed capital in the total tends to rise and that of net changes in inventories to decline.[1]

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1) KUZNETS, Simon: Modern economic growth, rate structure and spread, New Haven, 1966 (Yale University Press), p. 257.

(ii) The share of construction in both fixed capital formation and total capital formation declines and that of production equipment rises.[1)]

In individual countries others may be determined as well.

(c) Predicting exports

Over the long term, this is probably the most difficult component of the demand schedule to predict.

Even over the short term grave misgivings are expressed about the adequacy of any prediction. Nevertheless it has to be undertaken in order to obtain a comprehensive estimate of the future trends in economic and technological advance.

In predicting the export pattern over the long term the planners will have to take three factors into account:

(i) What the growth in world demand for various types of products is.

(ii) What the growth in local demand for various product types are.

(iii) Possible industrial strategy for the country, i.e. which industries will most likely provide the main export thrust. Various alternatives could be considered here and the implications of each examined.

E. Concluding remarks

On the basis of a long term forecast of technical coefficients, and a long term forecast of the demand vector, the calculation of a complete tableau

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1) Ibid., p. 257.

economique is a relatively straightforward and well known process which will not be discussed here.

We may now conclude this Section by stressing two observations. Firstly, it would seem impractical to try and integrate scientific planning with the conventional procedures of short term economic planning. An essential feature of these procedures is that they assume technology to be relatively stable.

Secondly, even if the period of economic planning is lengthened appreciably, for example to two decades, there is little apparent need to take account of individual developments in science. In fact the only problem about long term economic forecasting (apart from predicting the demand vector) lies in predicting future values for technical coefficients. Here, as we have seen, much can be accomplished by merely extrapolating past trends. This extrapolation may also be supplemented by (and compared with the results of) technological forecasting. But even technological forecasting proceeds in terms of its own system and does not call for particular knowledge about the progress of science.

From this analysis we may conclude that, at the present state of technological advance no compelling need exists to take account of specific scientific developments within a framework of long term economic planning. This would also seem to imply that long term economic planning procedures, as visualized in this Section, cannot be readily adapted into a system of scientific planning as well.

7.4 The merging of scientific and economic planning

In view of the reservations expressed in the previous Section it is appropriate that we ask at this stage whether any indications exist that a suitable methodology can be developed for combining scientific and economic planning into a unified system.

As far as the author could ascertain no such system has as yet been published (although research work in this area is proceeding at a number of institutions). The following comments are offered as guidelines to the type of system which could be contemplated.

A. Long term economic planning involving aggregate technological forecasting

If we assume that it is possible to construct a long term economic plan on the basis of a projected vector of final demand and a projected set of technical coefficients (extrapolated on the basis of past trends) we may argue that the projected change in each technical coefficient partially reflects the need for technological change in that sector. In other words it is an indication of what the sector has to accomplish technologically if the assumed overall rate of growth has to be achieved in practice.

This implied required level of technology could be achieved either by domestic technical advances or by relying on foreign developments. To the extent that the latter will involve substantial royalty payments to foreign suppliers, the development of home-grown technology could be seen as a technological objective closely linked with the economic objectives associated with the plan.

This technological objective could then serve as a target to be achieved by the country's scientific and industrial establishment and thus represents a goal in terms of which their activities could be planned.

While this method of approach holds sufficient promise to justify extensive further analysis, certain reservations come to mind which should be recorded here.

In the first place it is not as yet quite clear how the projected change in technical coefficients will be further analysed in order to identify technological goals - in other words how to move from an economic target to a technological target. And in the second place, even if a technologica target could be formulated, a whole new range of problems arise in connectio with the identification of scientific guide-lines. Among other things the technological target could call for, not science, but properly digested technical information or particular types of training. The possibility suggests itself therefore that the technological objective could form a central theme for various actions by the scientific-technical establishment of which scientific research could possibly be only one aspect.

Nevertheless these observations reinforce the importance of the suggested approach and emphasize the need for further analyses.

B. More remote possibilities

The ultimate procedure would be of course to merely formulate a certain desired demand vector and then employ a type of analysis which would indicate the required pattern of intersectoral transactions (including any required changes in the intensity of intersectoral purchases) and the required rate of technological advance. Possibly, too, a programming approach (of a higher order than linear programming) could be employed to determine some sort of optimum in intersectoral relationships and technological advance. From this point the analysis could proceed as discussed in the previous Sub-section.

Whether such an approach is in any way viable is uncertain at present. To determine whether it holds any promise would require a fundamental re-evaluation of matrix analysis and related mathematical techniques, as well as a re-examination of the framework of economic analysis in which they will be employed.

On the other hand future investigations may well prove that the basic concept of economic planning which we have used here is unsuitable to accommodate concepts of scientific planning. The final answer may quite well lie in a system of environmental and technological planning concentrating on the limitations posed by the availability of natural resources and the limits of existing technology. The extension of these boundaries could be defined as the objectives of science and individual research tasks could be mapped out from there. However it is difficult to foresee at this stage how such a planning system could be linked with the established procedures for economic planning.

Here, apparently, there is a fertile field for future investigations.

8. THE INTEGRATION OF SCIENTIFIC AND ECONOMIC PLANNING : TWO TECHNIQUES

8.1 Introductory remarks

While some of the basic problems of creating an integrated system of scientific and economic planning still remain unsolved, individual attempts have been made at developing, for particular needs, scientific planning techniques involving economic guidelines. Two of these will be briefly discussed as examples of the type of contribution being made.

The first is a contribution by a French research worker and represents a method of forecasting aggregate scientific requirements in association with a comprehensive economic forecast. The second is a method, developed in the Republic of South Africa, for allocating research priorities to industrial sectors.

Both these techniques assume a given rôle for research in the economy. In the first the research intensity of an economic sector is viewed as an inherent economic feature of that sector, while in the second it is seen as a possible stimulus to development.

These two attempts are recorded as part of the existing array of instruments which have been developed to meet specific needs in science planning. To an extent they are premature in that they imply the existence of a relationship which we are only beginning to understand. They are, however, extremely important as indications of the type of techniques which will no doubt abound once the fundamental relationship between science and economic growth is more firmly established.

8.2 A technique for predicting scientific needs in association with an overall economic forecast

A. Basic rationale

Recent research on the problem of integrating scientific and economic planning in France has yielded a technique, developed by Maestre,[1] for determining the "research content" of each sector of the economy, and, furthermore the relationship between this measure and scientific inputs in various branches of science.

The basic concept which Maestre tries to embody in his system is the notion that the relationship between inputs into a given scientific field and the eventual impact of that field on the economy is not a direct one. Research results from one field are sometimes more effectively absorbed and multiplied by the information distribution system than research results from another. In addition to this, interrelationships exist between various fields of science which can effectively inflate a given research input in one field of science into a significantly larger economic impact emanating ostensibly from another. By developing a model adequately reflecting these features Maestre has attempted to create an "élément méthodologique d'une stratégie nationale de la recherche".[2]

B. Description of procedure

(a) Tables showing interdependence between various scientific disciplines and between scientific disciplines and sectors of the economy

Essentially the Maestre method (as we will call the technique being studied) is based on the use of tables similar to those employed in input-output accounting, which show the quantitative relationships

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1) MAESTRE, Claude: "Vers une mesure des échanges intersectoriels entre la recherche et l'industrie", Le Progrès Scientifique, no. 102, Novembre 1966, pp. 2 - 44.

2) Ibid., p. 2.

between the inputs of science in specific disciplines, the influence which these inputs have on other disciplines, and eventually the inputs into various sectors of the economy. In Maestre's view certain sciences are more relevant to individual economic sectors than others, and expenditure of effort in one of these relevant disciplines will lead to an immediate and direct inflow of knowledge into a given economic sector. Other fields of science which are less closely related to particular sectors of the economy are required to "feed" those sectors which are so closely linked. Any discussion of the link between scientific effort and the benefits to the economy should therefore also take account of the interrelationships between the various disciplines of science itself.

The procedure followed by Maestre is as follows. First, a table is drawn up with an identical number of rows and columns corresponding to the number of scientific disciplines differentiated. These disciplines are arranged in order of increasing utility in an economic sense (in other words, in order of decreasing "fundamentality").

With the help of teams of experts in each discipline, the relative importance of various pairs of disciplines are then ranked in order of increasing relevance to each other. For this procedure one or more rows (depending on the degree of homogeneity) are considered simultaneously and the intensity of association between the disciplines represented by the rows and those represented in various columns identified. Next, the columns are ranked. In this way the question of interrelationships is looked at from two sides, namely: First, the extent to which the particular scientific discipline influences other disciplines, and second, the extent to which a given scientific discipline is influenced by others.

In the process of ranking the lowest value, 1, is given to those pairs of disciplines which have the closest association, and the highest value to those pairs of scientific disciplines which have the lowest association. Where no identifiable association exists the value given is zero. It is important to note that the entire table need not be ranked simultaneously. As long as the expert team can rank individual rows and columns it is possible (although the method is not described)[1] to "solve" the entire table, i.e. indicate the relative level of association between each pair of sectors. When this is done, we may say that the table is fully "ranked".

In much the same way as the relationship between various scientific disciplines is presented in tabular form and the degree of association indicated by a rank number, it is possible to indicate the association between various scientific disciplines and given sectors of the economy. If a table is drawn up with the rows corresponding to the various scientific disciplines, and the columns to the various sectors of the economy (which conveniently could correspond to the classification used in the country's economic input-output table) it should be possible to determine with expert advice, the degree to which various scientific disciplines are of importance to individual sectors of economy; and conversely, the extent to which certain sectors of the economy rely on progress in various scientific disciplines. Once the interdependence between scientific disciplines and economic sectors has been ranked for each row (or set of rows) and each column (or set of columns) this table may also then be fully ranked with the aid of an electronic computer.

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1) Maestre does not disclose the method of computation and all indication that he gives is that it has to be done on an electronic computer.

At this stage we have two tables, viz, first, a table showing the strength of association between various scientific disciplines, and second, a table showing strength of association between various scientific disciplines and sectors of the economy. For the sake of brevity these two tables will be referred to as the research/research (or R/R) table and the research/production (or R/P) table.

(b) Quantification of the products of research

Maestre's next step is to determine values representing the value of scientific effort, following from a given scientific input absorbed by various scientific disciplines (in the case of the R/R table) and by various sectors of the economy (in the case of the R/P table).

Unfortunately Maestre's exposé is neither sufficiently clear nor of required mathematical rigour, to enable us to present more than an outline of the procedure adopted by him.

Maestre claims that research effort in a given scientific discipline as measured in man-years, has an impact on other disciplines or sectors of the economy which may also be thought of in terms of so many man-years. On the basis of this notion Maestre claims that the impact which science in one discipline has on another discipline is a function of two variables viz (i) the original research effort in the given discipline, and (ii) the strength of association between that discipline and those which it influences. By the same token the impact on various economic sectors is some function of the extent of the original impact and the rank number indicating the degree of association between the scientific discipline and the sector in question.

Because Maestre's exact procedure is unclear to this author we will not attempt to describe it in any more detail and will have to content with drawing attention to one of its most important features. This is namely, that the impact of a given research effort (when the impact is measured in man-years) need not necessarily equal the original research effort measured in man-years. According to Maestre's system of allocation the impact of a given research effort may be less than the original effort and quite conceivably larger than the original effort. The latter Maestre explains by the phenomenon that the results of research are not consumed when they are applied. Consequently it is possible to apply the same results in various circumstances and also to duplicate the original research findings by means of various communications media.

(c) Allocating the cost of research in various disciplines to the different sectors of the economy

The third step in the Maestre method is to allocate the cost of research in the various disciplines to the various sectors of the economy. This is done by prorating the cost of research undertaken within the disciplines, on the basis of the man-year allocations (to the various sectors of the economy) which was explained in step two. The procedure Maestre follows is apparently a simple one of apportioning pro rata but at the same time he also discusses a fairly complex procedure for apportioning these costs also in the R/R Table. (However his motive for doing this is somewhat unclear.)

In this form the R/P Table gives an indication of the true research content of various sectors of the economy and therefore what their scientific needs are. This may be contrasted to the actual expenditure on research by each sector of the economy which is quite a different thing.

Once the true research content of each sector of the economy is known, it should be possible to predict future research requirements on the strength of an estimate of what the future structure of the economy will be. The result shows the required research input per discipline.

C. Assumptions on which such a projection is based

If the above method is to be used for the purposes of predicting future scientific needs, two basic assumptions are made.

First, that the relative strengths of association between the different disciplines can be determined, or at least agreed upon, by groups of experts. Second that the relative strengths of association between various scientific disciplines and the different sectors of the economy can similarly be determined or agreed upon. And third that these associations remain relatively stable during the period over which a prediction extends.

At this stage it is not possible to determine whether these assumptions are reasonable or not and consequently to what extent the Maestre method can be used in practice. What can be said about the model is that it incorporates some of the unique interrelationships between research and the economy, and that further studies, extending and refining these basic features, would probably contribute significantly to our ability to plan science effectively.

8.3 Allocation of research priorities to industrial sectors

A. Statement of the problem and general principles

One of the key problems facing governments who have taken it upon themselves to sponsor research because of its economic value, is the choice which they frequently have to make in allocating research priorities to various sectors of the economy. This problem could arise in a number of different settings.

First, it arises in those countries which have created national laboratories to undertake research with a view to contributing towards overall economic gains. The situation could very easily arise whereby the demands of the various institutes serving different sectors of the economy exceeded the volume of funds available. If this happens it would be necessary for the administrators to award priorities to the various sectors of the economy and distribute their funds accordingly.

In the second place the problem could arise whenever a government takes it upon itself to encourage co-operative research ventures within industry. Obviously the choice of which venture to support first involves the implicit allocation of priorities.

In the third place the problem would arise in those countries where it is the policy of government to render financial support to in-house research facilities of various industries. As long as the application for funds exceeded the amount of money available the decision of allocating priorities has to be made, whether implicitly or explicitly.

In this Section a method of approach is suggested for allocating priorities to various industrial sectors.[1] We cannot call it a methodology for it

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1) This procedure was first reported in: VAN WYK, R.J. and EATON, W.L.: The selection of sectors for techno-economic surveys, Pretoria, 1967 (Council for Scientific and Industrial Research). (Restricted circulation)

is not an infallible system. All it does is to offer a few simple guidelines. It is believed that by following these a quantitative appreciation of some of the most important aspects of priority allocation is obtained, and that this could contribute to a better decision than would be arrived at if all the factors now explicitly being considered had been allowed to accumulate in an intuitive judgement.

The principle thesis is that the sectors which are to receive the highest priority should at the same time be of great economic significance and have a relatively low research endowment when compared to their inherent technological need. In allocating priorities therefore attention should be given to three criteria, namely:

(i) Economic significance,

(ii) Inherent technological requirements,

(iii) Present research endowment.

Each of these will now be discussed in more detail.

B. Economic significance

(a) The concept of economic significance

There is no single and universally accepted measure of economic significance. In certain cases the sector may be said to be economically significant because of its size. At other times the employment opportunities which it offers are held up as an indication of its economic significance. Sometimes its exports are regarded as the key factor and sometimes the ability to "spark-off" economic activities in neighbouring sectors.

The important point is that economic significance depends to a large extent on the particular emphasis of economic policy and on the particular needs of a country at the given stage in its overall economic development. It follows therefore that the most significant sector would be one which ranks highest in terms of a given number of measures properly weighted in terms of their relative importance to the policy-maker, at the stage of development concerned.

Five such measures suggest themselves, namely:

(i) Size of the sector,

(ii) Expected future growth of the sector,

(iii) The sector's forward linkage,

(iv) The sector's backward linkage,

(v) The sector's share in contributing towards fixed capital formation,

(vi) The sector's share in contributing to exports.

Each of these will now be discussed.

(b) Criteria for economic significance

(i) Size

The size of the sector may be measured in terms of employment or contribution to gross domestic product. Not only does the size of the sector represent its economic bulk as such but it also emphasizes a magnitude of the social impact of any economic mishap which could befall the said sector.

(ii) Expected future growth

The second measure which suggests itself is expected future growth of the sector. This may be expressed conveniently in terms of percentage per annum which can be calculated from an input-output table whose technical coefficience have been properly adjusted to account for all expected changes in technology and for which a demand vector could be satisfactorily projected. The criteria of growth is selected for two reasons. Firstly it represents the future magnitude of the sector in question, and secondly it represents the forces of change per se which operate in the economy and require special attention from the policy-makers.

(iii) Backward linkage of the sector

Backward linkage is defined as the ratio of purchases from other sectors in the economy to the total purchases of the sector in question. The argument here is that a sector so linked with other sectors could have a secondary effect when economically stimulated. Consequently it is of greater general economic significance than a sector not having these ties and in whose case an increase in activity does not generate additional activity elsewhere in the economy.

Sectors with a high backward linkage are of course those whose "raw materials" are in themselves products of other sectors.

(iv) Forward linkage of the sector

Forward linkage may be defined as a ratio of sales to other sectors within the economy to total sales of the sector in question. Again the argument is that a sector whose final products constitute the raw materials for a succeeding sector can pass on economic benefits to other sectors of the economy.

Sectors with a high forward linkage are necessarily those whose final products constitute the raw materials of other sectors of the economy. Sectors whose main concern is the manufacture of goods for final consumption have a low forward linkage.

(v) Degrée to which products of a sector are employed in overall fixed capital formation

This value is merely the share of the sector's sales of investment goods in total fixed investment. This is regarded an important criterion insofar as new technology is frequently introduced into the economy by means of investment in new capital equipment. If the sales of the sector are an important share of overall fixed investment the sector has an economic value as a carrier of new technology.

(vi) Contribution to exports

The sixth criterion which suggests itself, is the sector's contribution to total exports. This is measured as that sector's share in the total export bill and the criterion is considered significant for any country experiencing balance of payments problems. In a country with a balance of payments surplus this criterion will be of less significance.

(c) Consolidation of measures into a single measure of economic value

Once it has been determined for each sector what its contribution to gross domestic product is, what its expected future growth rate is, what its forward linkage is, etc. the next step is to consolidate all these measures into a single expression of economic value. This can be done by introducing an arbitrary scoring system in terms of which a score is given to the sector in the light of its "performance" in contributing towards gross domestic product, expected future growth rate etc.

A number of scoring techniques can be thought of. The following one appears to have given fairly satisfactory results in practice.[1] The first step is to apply the six criteria of economic significance to each sector. This involves calculating for each sector those magnitudes - be they contribution to gross domestic product, contribution to exports, etc. which have been chosen as criteria for determining the economic significance of a sector. Taking these criteria one by one the value obtained by each sector is compared with the values obtained by every other sector and the sectors then ranked in terms of the values observed. The sector with the highest value is allocated the highest rank and the sector with the lowest value the lowest rank namely, one. In this way six series of rank values are obtained reflecting six "scores" for each sector in terms of each of the pre-selected criteria.

To obtain an aggregate value of economic significance for each sector it would of course, be possible to add together the six rank figures thus obtained. However, this would be tantamount to assuming that the six criteria carry equal weight irrespective of the point of view of government policy or the stage of economic development in which the country finds itself. It is necessary therefore, to select a given weight for each measure of economic significance and to apply this weight to the rank values obtained by the various sectors.

For each sector of the economy there now exists a series of six values representing the rank which was obtained by that sector (in terms of its "performance" in each of the six measures of economic significance,) and weighted in terms of the relative significance attached to each of the six measures employed.

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1) See Chapter 9, Section 9.2

By adding these six weighted ranks, a single consolidated figure for economic significance is obtained.

Although this is a fairly simple procedure, its verbal description is somewhat complex and it would be best to illustrate the procedure by means of a numerical example. As we propose to undertake such a calculation in Chapter 9, Section 9.2, we will not go into any more detail at this stage. We may turn our attention next to the determination of inherent technological need.

C. Determining inherent technological need

The determination of the technological need of a given sector differs essentially from the determination of its economic significance. Whereas the latter is concerned with describing a sector in terms of what it has achieved or could achieve in an economic sense, the former looks at the internal strains which this achievement will set up and which could possibly be alleviated by innovations brought about through scientific research. The basic principle therefore, is to look for significant structural changes which will occur in the sector during the planning period (i.e. the next one to two decades).

Apart from this it is also informative to investigate the research ratios of countries abroad, especially those which are more advanced, as this indicates very roughly the type of research input required to achieve the status of international acceptance in the industrial field in question.

(a) Structural changes expected

The investigation of this feature is of course limited to statistical data available. Four types of changes suggest themselves, namely,

(i) Changes in export ratios.

(ii) Changes in import ratios.

(iii) Changes in output labour ratios.

(iv) Changes in technical coefficients.

(i) Changes in export ratios

The export ratio of a sector is defined as the exports of that sector divided by imports plus domestic production. An increase in export ratio would suggest that industrial strategy requires the said sector to concentrate more on the export market and therefore suggest the need for a more refined technology in order to improve the sector's penetrative powers.

A decline in export ratios could suggest a loss in competitive advantage which in turn could indicate the need for more rapid innovation and scientific support, but it could also suggest that the sector has irrevocably lost its comparative advantage and that no more attention need be paid to it.

(ii) Changes in import ratios

The import ratio is defined as the ratio of imports to total domestic supply, which in effect equals imports plus domestic production. In the case of an increasing ratio, the question would arise as to whether the increase is due to a higher influx of competitive imports or of non-competitive imports. If the former is the case, such an increase ratio will indicate that the international competitive power of the sector has been adversely influenced, which could call for a re-deployment of scientific resources in order to bolster the sector's innovative ability.

A falling import ratio on the other hand, especially if the changing factor is due to competitive imports, could suggest a process of import substitution, which in itself can only proceed without special government protection if the competitive ability of local manufacturers is (nearly) as high as that of manufacturers abroad.

(iii) Changes in output/labour ratios

In practice it is doubtful whether a declining output/labour ratio will be observed, most of them will be increasing, some more rapidly than others. The most rapidly increasing output/labour ratios suggest that the particular sectors are either mechanizing very rapidly, or otherwise experiencing rapid growth in total factor productivity which in turn could indicate a need for scientific support.

(iv) Changes in technical coefficients

Significant changes in technical coefficients indicate technological trends which in turn could indicate scientific needs.

(b) <u>Overseas research and development ratios</u>

The research ratios of various economic sectors show an interesting international similarity. Deviations do occur of course, showing the slightly different emphasis which is laid on scientific research in various countries but in general there seems to exist a "research profile" which reflects the typical research intensities of different economic sectors.

This may be illustrated with reference to Tables XXVI, XXVII and XXVIII. The first table reflects research and development expenditure

TABLE XXVI

RESEARCH AND DEVELOPMENT IN AMERICAN INDUSTRY COMPARED WITH VALUE ADDED, 1958

Industry	Industrial research and development funds $ m	Value added $ m	Research and development expenditure as percentage of value added %
Total	8 246	150 092	5.5
Food and kindred products	83	17 259	0.5
Lumber, wood products and furniture	10	5 188	0.2
Paper and allied products	42	5 124	0.8
Chemicals and allied products	792	12 123	6.5
Industrial chemicals	553	6 529	8.5
Drugs and medicines	128	1 960	6.5
Other chemicals	111	3 634	3.1
Petroleum refining and extraction	246	11 591	2.1
Rubber products	89	3 247	2.7
Primary metals	119	12 329	1.0
Fabricated metal products	133	8 842	1.5
Machinery	781	11 821	6.6
Electrical equipment and communication	1 969	11 169	17.6
Motor vehicles and other transportation equipment	831	10 221	8.1
Aircraft and missiles	2 662	8 043	33.1
Professional and scientific instruments	294	2 935	10.0
Scientific and mechanical measuring instruments	156	1 188	13.1
Optical, surgical, photographic and other instruments	138	1 747	7.9
Other manufacturing industries	193	30 202	0.6

SOURCE: NATIONAL SCIENCE FOUNDATION, Industrial R and D funds in relation to other economic variables, Washington D.C., 1964 (N S F), pp. 6, 11 and 28.

TABLE XXVII

RESEARCH AND DEVELOPMENT EXPENDITURE IN BRITISH MANUFACTURING INDUSTRY

COMPARED WITH NET OUTPUT, 1955

Branch of manufacture	Net output 1)	Research and development expenditure	
	£ m	£ m	Per cent of net output
All manufacturing industries	7 772.0	296.7	3.8
All manufacturing industries except aircraft	7 492.1	196.7	2.6
Ceramics, glass, cement, etc. 2)	294.9	3.2	1.1
Chemicals and allied trades	734.9	43.0	5.9
Metal manufacture	703.6	8.1	1.2
of which: iron and steel	561.1	5.1	0.9
non-ferrous metal	142.4	3.0	2.1
Non-electrical engineering and shipbuilding 2))	2 251.6	(29.4	(1.8 4)
Electrical engineering and electrical goods 3))		(64.5	(11.8 4)
of which: electronics	206.2	29.6	11.9
Aircraft	279.9	100.0	35.7
Motor and other vehicles and accessories	519.6	17.1	3.3
Precision instruments, etc.	108.6	11.6	10.7
Textiles, leather, leather goods and clothing 5)	935.2	8.6	0.9
Food, drink and tobacco	940.0	5.0	0.6
Manufactures of wood and paper and printing	777.8	2.0	0.25
Other manufacturing	225.9	4.1	1.8

NOTES:

1) Net output represents the value added to materials by the process of production, including the gross margin of any merchanted or factored goods sold.

2) Includes metal goods not elsewhere specified.

3) Includes some mechanical engineering associated with electrical engineering where research and production in both fields are carried out in the same establishments.

4) Estimate.

5) Research and development expenditure for man-made fibres amounted to 14.0 per cent of the net output of these fibres, ignoring spinning and weaving.

SOURCE: GREAT BRITAIN, DEPARTMENT OF SCIENTIFIC AND INDUSTRIAL RESEARCH: Industrial research and development expenditure, 1958, London, 1960. (Her Majesty's Stationery Office).

TABLE XXVIII

EXPENDITURE ON RESEARCH AND DEVELOPMENT AS PERCENTAGE OF VALUE ADDED FOR VARIOUS BRANCHES OF INDUSTRY IN EUROPE AND THE U.S.A. (1963 - 1964)

SECTORS	GERMANY	FRANCE	BELGIUM	NETHER-LANDS	ITALY	U.S.A.
	%	%	%	%	%	%
A. Basic materials						
1. Ferrous metals	1.8	1.1	3.5	4.4	1.0	0.9
2. Non-ferrous metals	1.8	5.1	7.5	5.0	1.1	1.8
3. Stone, clay and glass	0.4	0.9	2.1	0.9	0.1	2.0
4. Metal manufactures	1.9	-	0.8	5.9	-	1.2
B. "Traditional" industries manufacturing consumption goods						
1. Foodstuffs and beverages	0.2	0.1	0.3	1.5	-	0.6
2. Tobacco	-	-	0.1	1.1	-	-
3. Textiles	0.4	0.8	0.4	1.6	-	)0.2
4. Footwear and clothing	0.3	-	0.1	0.3	-	)
5. Wood, cork and furniture	0.1	-	0.2	0.9	-	0.1
6. Paper	0.1	0.1	0.1	0.9	0.2	0.9
7. Printing and publishing	0.1	-	0.1	0.1	-	-
C. Chemical industries						
1. Petroleum extraction and refinery	2.0	1.8	1.5	1.3	0.8	4.5
2. Rubber products	1.7	1.2	)	3.6	6.4	3.0
3. Pharmaceutical products	)	6.2	)14.5	26.3	)	7.9
4. Other chemical industries	)8.6	3.2	)	12.7	)2.2	6.5
D. Mechanical and electrical manufactures						
1. Electrical machinery	4.1	8.8	5.1	8.3	1.3	14.7
2. Machinery (excluding electrical machinery)	2.4	0.6	1.9	7.2	0.5	5.2
3. Instruments	4.5	-	-	-	0.6	11.3
4. Aircraft and missiles	)	40.3	)	-	)	64.6
5. Vehicles and components	)	2.6	)	4.1	)	)
6. Shipbuilding	)1.6	-	) 1.0	4.5	)3.5	) 7.3
7. Other transport equipment	)	-	)	-	)	)
E. Other manufacturing industries	1.6	-	0.1	0.3	0.7	1.4

SOURCE: CONSEIL NATIONAL DE LA POLITIQUE SCIENTIFIQUE Recherche et croissance economique, Brussels, (CNPS) 1965, pp. 60 - 61.

in American industry as compared with value added for the year 1958. It will be noted that the most research intensive industries are: aircraft and missiles, with a research ratio of 33.1 per cent, electrical equipment and communication with a research ratio of 17.6 per cent, and scientific and mechanical measuring instruments with a research ratio of 13.1 per cent. In the case of Table XXVII research and development expenditure in British manufacturing industry is compared with net output during the year 1955. This table shows that the sector aircraft has a research ratio of 35.7 per cent, electronics, a research ratio of 11.9 per cent, and precision instruments a research ratio of 10.7 per cent. These ratios are all very similar to those observed in American industry during 1958. In the third table the research ratios of industries in various European countries are compared with one another as well as with those of American industry. Of particular interest in this table are the relatively high ratios for aircraft and missiles in the case of France and the U.S.A., namely, 40.3 and 64.6 per cent respectively.

The fact that this industry is not specified separately in the case of Germany, Belgium and Italy, is probably indicative of the relative unimportance thereof in the economies of these countries.

The ratios for electrical machinery are 14.7 per cent in the case of the U.S.A. and 8.8 and 8.3 per cent in the case of France and the Netherlands respectively. Unfortunately, no indication is given of the share of electronics within this category as this would significantly affect the research intensity of the sector.

A further trend which emerges is the emphasis which different countries place on research in different sectors. For instance, in the case of Belgium, the sector non-ferrous metals features as one of the most research intensive industries, while in the case of the Netherlands the research intensity of the chemical sector and in particular pharmaceutical products seems to be very much higher than that for any other country in the table.

From this we may conclude that although there exists a certain international research profile, changes in emphasis cause individual countries to deviate rather markedly from the mean. This would seem to indicate that depending on circumstances research could "pay off" in various industries and not only in those sectors which are normally regarded as highly research intensive. This leads one to believe that international trade strategy may demand different intensities in different countries to foster specialization and exports.

9. ECONOMIC APPROACH TO SCIENTIFIC POLICY AND PLANNING IN SOUTH AFRICA

9.1 Present use of economic advice and analysis

As a background against which actual South African experience in the use of economic analysis in scientific planning can be discussed we may begin with a brief, rather impressionistic review of the present use of economic analysis in scientific decision making in the Republic.

Most of the impressions recorded here are of a personal nature although they are substantiated, to a certain extent, by documentary evidence.

A. Policy-making level

(a) The Scientific Advisory Council to the Prime Minister

To begin at the highest policy-making level the memberships of the Scientific, as well as the Economic Advisory Councils were reviewed as at July, 1968. This showed that of the total memberships of forty-four in the case of the Scientific Advisory Council and of forty-nine in the case of the Economic Advisory Council only three persons served on both Councils.

From the available information on the membership of the Scientific Advisory Council, no provision is made for an *ex-officio* member of the Economic Advisory Council. One may conclude therefore that the cross representation which does exist is fortuitous rather than planned.

(b) Committee on Research Expenditure, a sub-committee of the Scientific Advisory Council (CORE)

The Committee on Research Expenditure functions as an expert group on the extent and composition of research and development expenditure in South Africa. It consists entirely of members of the Scientific Advisory Council, but on it serves also, *ex-officio*, the Deputy

Economic Adviser. Also the professional secretariat of CORE is taken from the Industrial Economics Division of the CSIR and consequently CORE has direct access to facilities for economic analysis.

(c) The Division of Scientific Planning of the Department of Planning

The executive arm of the government's scientific policy-making mechanism is the Division of Scientific Planning of the Department of Planning. The Department of Planning is so organized as to resort under a Secretary for Planning assisted by three Deputy Secretaries, namely; one for scientific planning, one for economic planning, and one for physical planning.

The Deputy Secretary for Scientific Planning is at the same time also the Deputy Scientific Adviser, while somewhat similar arrangements exist with respect to the Deputy Secretaries for Economic and Physical Planning. At the level of administering scientific policy, sufficient opportunities exist therefore for a cross-fertilization of science and economics. Unfortunately, no official record exists on the formal arrangements between these two Divisions, but it is clear that the facilities exist should they ever be required.

B. Major performers of research

(a) The Department of Agricultural Technical Services

No formal announcements could be traced of the explicit use of economic analysis in the planning of agricultural research and development. In the latest annual report covering the activities of the Department of Agricultural Technical Services, no indication is given of an economic staff or economic division performing such a function.[1)]

1) REPUBLIEK VAN SUID-AFRIKA, DEPARTEMENT LANDBOU TEGNIESE DIENSTE: Jaarverslag van die Sekretaris van Landbou-tegniese Dienste vir die tydperk 1 Julie 1966 tot 30 Junie 1967, Pretoria, 1968 (V & R Drukkery namens die Staatsdrukker).

This does not imply that the Department of Agricultural Technical Services conduct their research without taking account of economic priorities and economic needs. No doubt economic judgement and implicit economic evaluation does take place in deciding on research priorities, but no formal arrangements seem to exist therefor.

(b) Atomic Energy Board

Again no formal pronouncements have been made on the existence of an economics study unit or team concerned with scientific planning.

Nevertheless, it is clear from recent publications of the Board that long term economic considerations play an extremely significant part in selecting appropriate areas for development the Board's activities. A particular example which comes to mind is a report issued by the Board, and dealing with the possible utilization of nuclear power in South Africa for generating electricity.[1)]

(c) Council for Scientific and Industrial Research (CSIR)

The use of economic analysis in the planning of scientific research within the CSIR dates from approximately 1957 and is closely associated with the establishment of an Industrial Economics Division within the CSIR. The responsibilities of this Division have varied with time. At the time of writing they could be divided into three major categories.

(i) Research economics, which is concerned with the study of the extent and composition of expenditure on research and development in South Africa and the impact which this has on the

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1) RAAD OP ATOOMKRAG: Opsomming van die verslag oor n ondersoek na die moontlike aanwending van kernkrag in die Republiek van Suid-Afrika, Pelindaba, 1 Julie 1968 (RAK).

economy. The group performing this function are directly responsible to the Committee on Research Expenditure of the Scientific Advisory Council, but provide statistical services within the CSIR as well.

(ii) Industrial research development. In terms of this function the Industrial Economics Division undertakes a strategic overview of the economy and selects potential sectors which could benefit from the introduction of industrial research facilities. If the selection is approved by the CSIR Executive, techno-economic studies are then undertaken of the sectors thus identified and in each sector economically important research opportunities are sought for.

(iii) The Industrial Economics Division also provides economic services to the various institutes of the CSIR and in certain instances helps in evaluating the economic significance of alternative research programmes to assist in selecting the most appropriate area of investigation.

C. Others

As far as the other research organizations are concerned, such as the National Institute for Metallurgy and various government departments, no documentary evidence could be obtained of their reliance on economic procedures in scientific planning, and the general impression which exists is that formal economic procedures are not employed.

In the case of research departments within business enterprises it may be imagined that more formal economically based research planning procedures are employed - but these were not investigated.

In the next two Sections attention is given to two aspects of the methodology for planning scientific research in terms of economic guidelines. The first is concerned with the allocation of research priorities to various industrial sectors, while the second is concerned with the identification of economically significant research opportunities within these sectors.

9.2 Selection of sectors for techno-economic surveys

A. Background

This procedure was developed by the author while employed in the Industrial Economics Division of the CSIR. Primarily it is intended to assist the Advisory Committee for the Development of Research for Industry in selecting which industrial sector should receive priority as a subject for a techno-economic survey. The approach was first published in 1967 in an internal CSIR report[1)] and has since then been revised somewhat.[2)]

The general features thereof have already been discussed in Chapter 8 Section 8.3. In this Section an attempt is made to illustrate the approach with the aid of South African data.

Two limitations should, however, be taken note of. First, no comprehensive long term projection is available for the South African economy so that all estimates of future growth rates required in the analysis are based on short term estimates, i.e. those presented in the Economic Development Programme. Second, at the time of writing, the latest statistical data available for applying the approach were those contained in the Economic Development Programme for the Republic of South Africa 1966/71. This implies that the most recent data available referred to 1965. Although a new Programme covering the period 1968/73 was expected during December 1968, it was too late for the purposes of the present dissertation. The following example is therefore based on somewhat outdated statistics. Nevertheless it serves to illustrate the procedure.

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1) VAN WYK, R.J. and EATON, W.L.: op. cit.

2) In this connection, I gratefully acknowledge the comments of Prof. J.L. Sadie However, many of the problems identified by him still remain.

B. Determination of economic significance

(a) Methodology

The method is the same as that described in Chapter 8 Section 8.3 and it will not be repeated here. The same six criteria are used, namely; contribution to gross domestic product, expected growth, forward linkage, backward linkage, use of sector's output in overall capital formation, and contribution to exports. For the purpose of the present calculation these six measures of economic significance are weighted according to the pattern; 0.25, 0.25, 0.1, 0.1, 0.1 and 0.2 respectively. It is not claimed that these are necessarily the correct weights.

Thirty-four sectors are differentiated corresponding to the number in the Economic Development Programme for the Republic for the period 1966/71.

(b) Results of the calculations

The results of the calculations are shown in Table XXIX. The six criteria of economic significance as well as their respective weights are shown in the column headings across the top of the table. The total column is on the extreme right hand of the page and contains for each sector, a score reflecting the "economic significance" of the sector (in terms of the criteria and assumptions chosen). This score is the sum of six individual values calculated for each sector by taking its rank values for each of the six criteria, and multiplying these with the weight given to the particular criterion.

In theory the maximum score obtained for a given sector would approach 34, while the minimum score would approach 1. In terms of the calculations made the total scores were distributed around a mean value of 17.3 with a standard deviation of 5.0. The distribution did not deviate too much from normality but was skew in the direction of the lower values with a cluster at the higher values.

Those sectors which had a score of higher than the mean plus one deviation were sector 7, textiles, with a value of 24.7; sector 21, basic iron and steel industries, with a value of 24.1; sector 23, metal products (excluding machinery and transport equipment), with a score of 23.5; sector 17, basic industrial chemicals, with a score of 23.0; sector 24, machinery (excluding electrical machinery), with a score of 22.9; and sector 1, agriculture, forestry and fisheries, with a score of 22.7.[1)]

Other sectors falling within the top third are; sector 19, products of petroleum and coal, with a score of 22.0; sector 27, motor vehicles, with a score of 21.9; sector 13, pulp and paper products, with a score of 21.4; sector 33, transport and communication, with a score of 21.0; and sector 18, miscellaneous chemical products, with a score of 20.5.

C. Determination of inherent technological need

As pointed out in Chapter 8, Section 8.3 the determination of inherent technological need is based on two indicators, namely, first, large predicted changes in certain quantitative ratios in the various sectors, and second, research ratios observed for countries abroad.

Because no long term forecast of the South African economy is available the first indicator could not be used and we have relied exclusively on overseas ratios as presented in Chapter 8, Section 8.3 C (b). These will not be repeated here.

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1) If the different criteria are given equal weights and the top six sectors selected anew, all the above appear again except agriculture forestry and fisheries which is replaced by motor vehicles.

TABLE XX1X

CALCULATING THE ECONOMIC SIGNIFICANCE OF VARIOUS SECTORS OF THE ECONOMY

Sector of the economy	CONTRIBUTION TO GROSS DOMESTIC PRODUCT			EXPECTED GROWTH RATE FOR 5 YEAR PERIOD			SALES BY SECTOR USED IN GROSS FIXED CAPITAL FORMATION			CONTRIBUTION TO EXPORTS			FORWARD LINKAGE			BACKWARD LINKAGE			TOTAL
	Value	Rank	Rank multi-plied by weight Of 0.25	Rate	Rank	Rank multi-plied by weight of 0.25	Amount	Rank	Rank multi-plied by weight of 0.1	Value	Rank	Rank multi-plied by weight of 0.2	Ratio	Rank	Rank multi-plied by weight of 0.1	Ratio	Rank	Rank multi-plied by weight of 0.1	
1. Agriculture, forestry and fisheries	850.9	32	8.0	5.8	16	4.0	0	14	1.4	223	32	6.4	.56	20	2.0	.22	9	0.9	22.7
2. Gold mining (including uranium)	607.8	30	7.5	0.9	1	0.3	0	14	1.4	810	34	6.8	.20	5.5	0.6	0	1	0.1	16.7
3. Coal mining	64.4	18	4.5	6.3	22	5.5	0	14	1.4	4	11	2.2	.87	31	3.1	.09	4	0.4	17.1
4. Other mining and quarrying	307.6	28	7.0	4.9	11	2.8	0	14	1.4	254	33	6.6.	.40	15	1.5	.14	6	0.6	19.9
5. Processed foodstuffs (excluding beverages)	144.9	25	6.3	4.6	7	1.8	0	14	1.4	166	31	6.2	.21	7.5	0.8	.71	34	3.4	19.9
6. Beverages and tobacco	45.8	10	2.5	4.7	8	2.0	0	14	1.4	5	13.5	2.7	.20	5.5	0.6	.51	27	2.7	11.9
7. Textiles	71.6	20	5.0	8.5	31.5	7.9	0	14	1.4	28	25	5.0	.62	23	2.3	.56	30.5	3.1	24.7
8. Knitting mills	20.0	2	0.5	5.8	16	4.0	0	14	1.4	2	7	1.4	.17	4	0.4	.44	19	1.9	9.6
9. Clothing	67.8	19	4.8	4.2	5	1.3	0	14	1.4	6	16.5	3.3	.03	2	0.2	.48	25.5	2.6	13.6
10. Footwear	26.7	4	1.0	4.0	4	1.0	0	14	1.4	2	7	1.4	.04	3	0.3	.42	17.5	1.8	6.9
11. Wood and wood products (ex-cluding furniture)	34.3	8	2.0	4.5	6	1.5	0	14	1.4	1	4.5	0.9	.93	33	3.3	.39	14	1.4	10.5
12. Furniture and fixtures	42.9	9	2.3	4.8	9.5	2.4	0	14	1.4	3	9	1.8	.22	10	1.0	.37	12	1.2	10.1
13. Pulp and paper products	61.7	17	4.3	7.3	24	6.0	0	14	1.4	20	23	4.6	.86	30	3.0	.45	21	2.1	21.4
14. Printing, publishing and allied industries	57.5	15	3.8	7.4	25	6.3	0	14	1.4	6	16.5	3.3	.69	25	2.5	.30	10	1.0	18.3
15. Leather and leather products (excluding footwear)	5.8	1	0.25	3.0	2	0.5	0	14	1.4	1	4.5	0.9	.72	26	2.6	.45	21	2.1	7.8

Sector of the economy	CONTRIBUTION TO GROSS DOMESTIC PRODUCT			EXPECTED GROWTH RATE FOR 5 YEAR PERIOD			SALES BY SECTOR USED IN GROSS FIXED CAPITAL FORMATION			CONTRIBUTION TO EXPORTS			FORWARD LINKAGE			BACKWARD LINKAGE			
	Value	Rank	Rank multi-plied by weight of 0.25	Rate	Rank	Rank multi-plied by weight of 0.25	Amount	Rank	Rank multi-plied by weight of 0.1	Value	Rank	Rank multi-plied by weight of 0.2	Ratio	Rank	Rank multi-plied by weight of 0.1	Ratio	Rank	Rank multi-plied by weight of 0.1	TOTAL
16. Rubber products	29.3	5	1.3	6.1	21	5.3	0	14	1.4	4	11	2.2	.73	27	2.7	.46	23.5	2.4	15.3
17. Basic industrial chemicals	47.8	11	2.8	8.7	33	8.3	0	14	1.4	23	24	4.8	.78	28	2.8	.52	28.5	2.9	23.0
18. Miscellaneous chemical products	56.6	13	3.3	8.2	30	7.5	0	14	1.4	17	21.5	4.3	.54	19	1.9	.45	21	2.1	20.5
19. Products of petroleum and coal	57.2	14	3.5	11.0	34	8.5	0	14	1.4	12	19	3.8	.58	22	2.2	.48	25.5	2.6	22.0
20. Non-metallic mineral products	82.6	21	5.3	4.8	9.5	2.4	0	14	1.4	5	13.5	2.7	.90	32	3.2	.38	13	1.3	16.3
21. Basic iron and steel industries	129.9	24	6.0	8.0	29	7.3	0	14	1.4	46	27	5.4	.79	29	2.9	.35	11	1.1	24.1
22. Non-ferrous metal basic industries	20.3	3	0.8	8.5	31.5	7.9	0	14	1.4	2	7	1.4	.96	34	3.4	.57	32	3.2	18.1
23. Metal products (excluding machinery and transport equipment)	166.5	26	6.5	6.0	19.5	4.9	115	31	3.1	15	20	4.0	.57	21	2.1	.52	28.5	2.9	23.5
24. Machinery (excluding electrical machinery)	99.0	23	5.8	7.8	27.5	6.9	381	33	3.3	17	21.5	4.3	.21	7.5	0.8	.42	17.5	1.8	22.9
25. Electrical machinery and equipment	51.5	12	3.0	7.8	27.5	6.9	111	30	3.0	4	11	2.2	.36	14	1.4	.56	30.5	3.1	19.6
26. Transport equipment (excluding motor vehicles)	32.1	7	1.8	5.8	16	4.0	73	29	2.9	6	16.5	3.3	.22	10	1.0	.46	23.5	2.4	15.4
27. Motor vehicles	59.0	16	4.0	7.6	26	6.5	135	32	3.2	6	16.5	3.3	.41	16	1.6	.69	33	3.3	21.9
28. Miscellaneous manufacturing industries	31.8	6	1.5	5.9	18	4.5	13	28	2.8	30	26	5.2	.22	10	1.0	.40	15	1.5	16.5

.../3

Sector of the economy	CONTRIBUTION TO GROSS DOMESTIC PRODUCT			EXPECTED GROWTH RATE FOR 5 YEAR PERIOD			SALES BY SECTOR USED IN GROSS FIXED CAPITAL FORMATION			CONTRIBUTION TO EXPORTS			FORWARD LINKAGE			BACKWARD LINKAGE			TOTAL
	Value	Rank	Rank multiplied by weight of 0.25	Rate	Rank	Rank multiplied by weight of 0.25	Amount	Rank	Rank multiplied by weight of 0.1	Value	Rank	Rank multiplied by weight of 0.2	Ratio	Rank	Rank multiplied by weight of 0.1	Ratio	Rank	Rank multiplied by weight of 0.1	
29. Construction	401.2	29	7.3	3.7	3	0.8	877	34	3.4	0	2	0.4	0	1	0.1	.41	16	1.6	13.6
30. Electricity, gas and water	168.4	27	6.8	6.0	19.5	4.9	0	14	1.4	0	2	0.4	.63	24	2.4	.11	5	0.5	16.4
31. Trade (wholesale and retail)	1130.5	33	8.3	5.3	12.5	3.1	0	14	1.4	66	28	5.6	.23	12	1.2	.04	2	0.2	19.8
32. Motor trade and repairs	90.8	22	5.5	7.0	23	5.8	0	14	1.4	0	2	0.4	.42	17	1.7	.17	8	0.8	15.6
33. Transport and communication	613.9	31	7.8	5.5	14	3.5	0	14	1.4	70	29	5.8	.45	18	1.8	.16	7	0.7	21.0
34. Miscellaneous services	1813.3	34	8.5	5.3	12.5	3.1	0	14	1.4	88	30	6.0	.28	13	1.3	.08	3	0.3	20.6

NOTE: The notation - indicates that the value is 0.
The notation .. indicates that the value is less than half of one unit of the measure employed.

D. <u>Local research ratios as compared with overseas ratios</u>

The research ratios of the various sectors of the South African economy are presented in Chapter 4, Section 4.3. From these data, and those on research ratios abroad presented in Chapter 8, Section 8.3 C (b) Table XXX has been compiled which compares research ratios for various economically important sectors in South Africa with the research ratios of similar sectors abroad.

It will be noted that with the exception of sector 13, <u>pulp and paper products</u>; sector 7, <u>textiles</u>, and sector 19, <u>products of petroleum and coal</u>, which fall within the range of overseas research ratios (and in the case of the latter two only just!), all the other sectors for which roughly comparable data could be obtained had (sometimes significantly) lower research ratios than those in countries abroad.

The most striking discrepancies occurred in three sectors; sector 23, <u>metal products (excluding machinery and transport equipment)</u>; sector 24, <u>machinery (excluding electrical machinery)</u>; and sector 27, <u>motor vehicles</u>. Significant discrepancies also occurred in sector 17, <u>basic industrial chemicals</u>, and sector 18, <u>miscellaneous chemical products</u>. Another sector to which attention may be drawn is sector 19, <u>products of petroleum and coal</u>. Although the South African research ratio of 0.8 per cent is within the range observed for more developed countries, namely 0.8 to 4.5 per cent, the technology employed in South Africa in extracting petroleum products from coal may be regarded as highly research intensive and the question may be asked as to whether the ratio observed reflects an adequate level of research support?

TABLE XXX

COMPARISON BETWEEN RESEARCH RATIOS IN SOUTH AFRICA AND THOSE FOR A NUMBER OF COUNTRIES ABROAD

		Range of research ratios for developed countries	South African research ratios
Sector 7	Textiles	0.4 - 1.6	0.4
Sector 21	Basic iron and steel industries	0.9 - 4.4	0.7
Sector 23	Metal products (excluding machinery and transport equipment)	0.8 - 5.9	0.1
Sector 17	Basic industrial chemicals	± 3.0 - 12.7	2.5
Sector 24	Machinery (excluding electrical machinery)	0.5 - 5.2	0.1
Sector 1	Agriculture	?	1.3
Sector 19	Products of petroleum and coal	0.8 - 4.5	0.8
Sector 27	Motor vehicles	± 2.6 - 4.1	0.1
Sector 13	Pulp and paper products	0.1 - 0.9	0.3
Sector 33	Transport and communication	?	..
Sector 18	Miscellaneous chemical products	Indistinguishable from basic industrial chemicals. Except pharmaceutical products 6.2 - 26.3	0.7

D. Concluding remarks

Following the procedure outlined in Chapter 8, Section 8.3, for allocating research priorities to various sectors of the economy, and subject to the qualifications mentioned at the beginning of the present Section, the following sectors may be identified as priority sectors for any steps to encourage industrial research:

- Metal products (excluding machinery and transport equipment).
- Machinery (excluding electrical machinery).
- Motor vehicles.
- Basic industrial chemicals.
- Miscellaneous chemical products.
- Products of petroleum and coal.
- Textiles.

Bearing in mind the heavy research requirements of the following sectors (as yet not significant in South Africa) their potential emergence as high priority sectors should not be lost sight of:

- Electronics (especially the production of mini-automats suited to the limited needs of a developing country;
- Aircraft manufacture; and
- Instrument manufacture.

9.3 Techno-economic surveys

A. Object and method of approach

The task of a techno-economic survey, as defined by the Industrial Economics Division of the CSIR, is to determine whether economically significant research opportunities exist in given sectors of industry. Strictly speaking it has a very limited objective therefore in that it is primarily concerned with identifying research tasks.

A number of these surveys have already been undertaken in South Africa,[1] and certain general trends regarding their nature may be distinguished.

First, the surveys do not seem to look for pre-conceived indicators of research opportunities, such as trends in efficiency ratios, trends in technological development, or other similar guides. It would seem therefore that in the case of these surveys the ability to identify research tasks is left to the ingenuity of the survey team rather than to a particular methodology for identifying such problems.

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1) VAN DER WALT, D.G., LOUW, D.F., and BOSHOFF, A.B.: The research needs of the South African textile industry - a techno-economic survey, Pretoria, 1965 (Council for Scientific and Industrial Research) (CSIR Special Report info 19).

VISSER, J.H.: The research needs of the South African forest products industry - a techno-economic survey, Pretoria, 1966 (Council for Scientific and Industrial Research) (CSIR Special Report info 20).

VAN DER WALT, D.G., ZULCH, B.J., and MINNAAR, A.C.: The research needs of the motor component manufacturing industry in South Africa (with special reference to ferrous metals) - a techno-economic survey, Pretoria, 1966 (Council for Scientific and Industrial Research) (IED/3/66).

ZULCH, B.J., MINNAAR, A.C., and EATON, W.L.: The research needs of the metals engineering industry in South Africa - a techno-economic survey, Pretoria, 1967 (Council for Scientific and Industrial Research) (CSIR Special Report Info 266).

MINNAAR, A.C., and PEPLER, L.A.: The research needs of the packaging industry in South Africa - a techno-economic survey, Pretoria, 1968 (Council for Scientific and Industrial Research) (IED/11/68).

The second feature of these surveys which may be remarked upon is the extent to which technical problems, other than purely research problems, are readily identified. In fact the techno-economic survey in its present form seems to be better suited to the identification of technical problems rather than research opportunities.

As will be noted below, it is nevertheless believed that the survey teams have been reasonably successful in identifying problems for research, and this may be described to the particular qualities of the team and their composition rather than to the method employed. In general the teams were of a multi-disciplinary nature. In one case the team consisted of an industrial economist, an industrial psychologist and a production engineer with managerial training. In another case the team consisted of a production engineer with managerial training, a certified draughtsman with long experience in the sector being studied and a statistician with economic experience. Also it has been the practice to co-opt members on survey teams whenever it was felt that further specialist skills were required.

B. The value of techno-economic surveys

(a) Identifying research needs

In general the survey teams have succeeded in identifying a rather wide range of research opportunities. In the study of the research needs of the metals engineering industry for example, it was found that the major need which existed was for research into production engineering. The central phenomenon was that production runs in South Africa, as a result of the limited market, are somewhat smaller than production runs in more industrialized countries. Production equipment, however, is designed for the longer production runs common to overseas countries, causing a cost disadvantage to the South African manufacturer.

Apart from identifying the above problem, which may be regarded as the central problem in the metals engineering industry, the survey team pointed to various other possible fertile fields for research. To quote from the report; "One manufacturer was unsure of the ageing characteristics of materials (non-metals) which were being used in the manufacture of transformers. This was mainly the case where newly developed materials were being used. He would have liked to discover a method of artifically ageing these materials." And another example; "A manufacturer of electrical machinery stated that the effects of changes in atmospheric conditions on the performance of materials used in the manufacture of electrical machines were very much an unknown quantity."[1)]

In the report dealing with the research needs of the motor components manufacturing industry in South Africa, various possibilities for research are suggested. The following are a few examples. Regarding the use of mild steel the report says: "This material is used for the manufacture of small component parts in single and multi-spindle automatic lathes, and in both hexagonal and round form. It is required to have good free cutting qualities in order to utilize to the full extent the mass-production capabilities of the automatic machines. In the case of one manufacturer, however, the use of locally produced free cutting steel necessitated a reduction in cutting speed of 25% in relation to that of imported free cutting steel, with a proportional drop in production."[2)] It is suggested that economic benefits could be derived from research into the free cutting qualities of South African mild steel.

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1) ZULCH, B.J., MINNAAR, A.C., and EATON, W.L.: op. cit. p. 56.

2) VAN DER WALT, D.J., ZULCH, B.J., and MINNAAR, A.C.: op. cit. p. 35.

It must be stressed however, that the success of the techno-economic survey is entirely dependent on the ingenuity of the survey team. Frequently it is their task to search out problems in areas where industry assumes no problems exist. It has been found for instance that a certain undesirable condition which exists for a long period is accepted by industry as a fact of life and not as a variable which can be influenced by scientific research. In such cases it is only the insight of the survey team which ensures that problem areas are identified.

(b) Identifying other technical problems apart from research needs

But apart from the possibility of identifying possible areas for research by means of a techno-economic survey the survey also yields information on other technically rooted problems of economic importance. As an example: "Universal concern was expressed at the number of steel specifications found in the metal industry. A few of the more prominent ones were, the En series, the DTD series, DIN, Werkstoff, AISI and SAE. Doubtless the existence of these recognized specifications can be justified in some way or another, but it is difficult to justify the fact that, in addition to this, many manufacturers of steels establish their own standards or at least rename the steels, which all adds to the confusion."[1) In this connection the techno-economic survey has pointed to, not a research problem, but one of standardization. Many more examples of this kind can be quoted and the general impression is that the techno-economic survey provides an ideal medium for the identification of such technically rooted problems of economic importance.

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1) ZULCH, B.J., MINNAAR, A.C., and EATON, W.L.: op. cit. p. 56.

C. Shortcomings of the techno-economic survey

Probably the main shortcoming of the techno-economic survey is the fact that it is geared to uncovering existing problems in existing manufacturing procedures rather than to indicate possible future developments on the basis of technological projections. In other words, no attempt is made at technological forecasting although this is an ideal place to undertake such an exercise. It may be suggested that future techno-economic surveys give more attention to this aspect.

The second main shortcoming of the techno-economic survey is the manner in which possible areas for research are indicated. These research problems are not described in sufficient technical detail to enable an uninitiated research worker to proceed immediately with the appropriate investigations. The surveys tend to be more useful for research management than for the research scientists themselves. Where a research institute already exists which has some scientific knowledge of the field investigated, the survey admirably fulfils the function of focussing management's attention on the appropriate problems. Where research facilities do not yet exist, the survey provides an inadequate base for the start of the research programme. This is said for two reasons. First, because very few, if any, of the surveys give an indication of the relative economic importance of the alternative problem fields identified. Consequently they give no indication of relative priorities in research. Second, as stated before, the surveys identify problem areas and not research tasks.

Nevertheless it is believed that the surveys have proved an extremely useful tool in associating scientific research more closely with economic needs. By extending the scope of the survey to incorporate a measure of technological forecasting their value should increase even more. In this connection consideration could be given to the construction of simple mathematical production models[1)] to identify significant parameters in the production processes of various branches of industry. On the basis of these simple models technological forecasts i.e. forecasts of shifts in parameters, could be attempted in an effort to identify promising areas for innovation.

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1) As a guide to these models see: CHILTON, Cecil H.: Cost engineering in the process industries, New York, Toronto, London, 1960 (McGraw Hill Book Company Inc.)

PART IV

CONCLUDING REMARKS

10. CONCLUSIONS AND RECOMMENDATIONS

10.1 Conclusions

A. Conclusions arrived at in Part I

From a review of the theory dealing with the relationship between scientific research and economic growth, it is evident that scientific research has the effect of extending the range of innovational opportunities by making innovators aware of many more features of nature than would have been known had science not rendered them comprehensible. In this way possibilities are created for economic growth. In the more economically advanced countries these possibilities are so habitually exploited that the growth rates observed are dependent on the insights provided by research. Research commitments therefore constitute a necessary condition for these economies to expand at the rates we have become accustomed to.

However, it would be incorrect to assert that because such a relationship exists, large scale expenditure on science will always generate economic growth.

This would only occur if certain very special conditions prevail in the economy. Essentially these are: The research intensive industries should constitute a dominant force in the economy. The research expenditure by government should be in fields falling within the sphere of interest of these industries (and preferably on problems bearing relation to given industrial constraints). A technological capability must exist within industry to ensure an absorbtive capacity for science. Industry must have attained a minimum critical size to maintain and operate a development division of sufficient size to carry out the costly and risk bearing task of bringing a scientific discovery to technical fruition and commercial viability.

Few countries meet these unique requirements. While research does not directly and inevitably lead to aggregate economic advance, it does under certain circumstances generate isolated economic benefits. These opportunities have to be carefully sought out and exploited.

As far as the analysis of overall research benefits is concerned, it is found that an aggregate production function does not provide an adequate conceptual framework for visualizing the economic impact of science. A more complex model is required.

B. Conclusions arrived at in Part II

This part is devoted to a review of the growth of science in South Africa, the current expenditure on research in the Republic, and the impact of science on the South African economy.

It is suggested that the development of the research establishment follows a given pattern. During the first stage, scientific research was virtually limited to individual scientists (mostly) attached to university departments and museums. During the second, mission oriented research organizations were established within government departments or in the form of statutory councils. The third stage saw the establishment of industrial research facilities of various types. It is believed that the Republic is still in this stage of evolution and that industrial research facilities will expand rapidly in the near future.

As far as expenditure on research and development is concerned the Republic spent approximately R37 million during the financial year 1966/67 and the academic year 1966. This amounted to 0.5 per cent of gross national product at market prices. In comparison with more economically advanced countries whose research ratios are in the region of 2 per cent (and in the case of America 3.2 per cent) the South African research ratio is relatively low. However, this ratio compares well with the ratio for countries at a comparative stage of economic development.

As far as the economic impact of South African scientific research is concerned, it may be concluded that this has probably not been a significant factor in overall economic advance in the Republic - although it has played an important rôle in agriculture and mining. The manufacturing sector relies very heavily on the importation of technical know-how from overseas, and available statistical evidence suggests that industry relies on local science to a very limited degree only. Nevertheless examples may be cited of instances where scientific research in the industrial sector has yielded significant economic advantage.

It is argued that the present relatively low research endowment is a feature of an economy in the stage of development in which the South African economy finds itself. However, expected future trends in South African economic development are such as to emphasize the need for building up an export potential based on industry's ability to innovate. This could possibly be achieved by encouraging the establishment of research groups within individual industrial enterprises and by offering some sort of financial assistance for the development of advanced products and processes. Specific recommendations are made in this connection.

C. <u>Conclusions arrived at in Part III</u>

The third part of the dissertation is concerned with the economic approach (and the use of economic techniques) in scientific policy-making and planning.

When cast in a particular framework the central issues in scientific policy-making are reduced to the problem of correctly allocating research resources in order to meet given pre-selected social objectives (weighted to reflect their relative importance) and subject to certain constraints, imposed, for instance, by the limited resources available. This formulation is strongly suggestive of a linear programming approach. While it is doubtful whether linear programming could, in practice, be successfully applied to this field, it does provide an interesting conceptual framework within which various issues of scientific policy may be considered.

As far as planning for science within a recognized system of economic planning is concerned, it appears highly unlikely that the current techniques of indicative economic planning are capable of reflecting the concepts and magnitudes associated with scientific planning. Part of the problem would seem to lie in the short period involved in economic planning (usually five years) while the impact of science is usually felt after a much longer period. However even the lengthening of the economic planning period (to a period of, say, two decades) does not automatically create the need for considering developments in science. Long term economic planning could probably proceed on the strength of its own unique system (involving inter alia aggregate technological forecasting) without requiring an awareness of developments in the field of science. On the other hand indications are that a comprehensive plan for science could emerge from a system of planning which highlights environmental and technological constraints. This promises to be a most fertile field for further investigations.

Part III concludes with a Chapter dealing with two techniques for planning certain aspects of science on the basis of economic guidelines, and a

Chapter on South African experience in this field. These discussions suggest the emergence of a useful and growing methodology for planning scientific research in terms of economic objectives

10.2 Recommendations

A. Recommendations for future study

(i) It is recommended that priority be given to a series of selected case studies of South African scientific discoveries which have achieved economic success. This is needed for a fuller understanding of the manner in which science affects the economy. Attempts to undertake a survey of this nature in the past have met with much opposition and more often than not the data obtained were entirely unsatisfactory. Future surveys will not be easy but the data would be extremely valuable.

(ii) Next an attempt should be made to construct a formal conceptual model reflecting the various routes along which science exerts an economic influence. Furthermore the model would reflect the pattern of international technological flows and recognize the different technological requirements of an economy at various stages of development.

(iii) Further investigations are called for concerning the integration of scientific and economic planning. One possible avenue to explore would be the lengthening of the period of economic planning and the identification of technological goals. A more promising procedure however would seem to lie in a system which highlights environmental and technological constraints, the removal of which may then be defined as the objectives of the scientific and technical community.

(iv) Further analysis is required to develop an appropriate classification of the main issues of scientific policy-making and to present these in a framework which can serve as a basis for practical policy decisions.

(v) A thorough re-evaluation of the "Maestre method" is called for.

B. Recommendations for government action

(i) It is recommended that consideration be given to the establishment of a number of assistance schemes for encouraging industries to establish their own research facilities and to attempt the development of new products and processes. Initially a small amount need be set aside for this purpose (i.e. approximately R1.5 million per annum for the first five year period). This recommendation is subject to a re-evaluation of the present industrial structure in South Africa (to determine the size distribution of industries and the extent of foreign control) to ensure that South African industry would benefit sufficiently from the schemes proposed.

(ii) It is further recommended that the infrastructure of the South African economy be re-examined to determine whether the current research support is adequate to meet future demands. Housing, transportation, the optimum use of water resources, and the rational exploitation of energy sources are all areas which, it is expected, will call for rapid technological advance.

(iii) Finally it is recommended that the research activities pertaining to the sector agriculture forestry and fisheries be re-evaluated. The high research intensity of the said sector signifies the need for ensuring the optimum utilization of research funds.

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Appendix A.

LIST OF RESEARCH INSTITUTES FUNCTIONING IN SOUTH AFRICA

(An asterisk indicates that the organization was included in the survey of expenditure on research and development in South Africa during the financial year 1966/67 and the academic year 1966.)

A. GOVERNMENT SECTOR

(a) Government departments

Government departments performing research:

(i) Department of Agricultural Technical Services.*
(ii) Department of Bantu Administration and Development.*
(iii) Department of Forestry.*
(iv) Government Printing Works.*
(v) Department of Industries.*
(vi) Department of Mines.*
(vii) National Parks Board of Trustees.*
(viii) Department of Posts and Telegraphs.*
(ix) South African Railways and Harbours Administration.*
(x) Department of Transport.*
(xi) Department of Water Affairs.*

The Department of Agricultural Technical Services controls the following specialized research institutes:

(i) Animal Husbandry and Dairy Research Institute.
(ii) Botanical Research Institute.
(iii) Citrus and Subtropical Fruit Research Institute.
(iv) Fruit and Food Technology Research Institute.
(v) Horticultural Research Institute
(vi) Plant Protection Research Institute.
(vii) Soils Research Institute.
(viii) Tobacco Research Institute.
(ix) Veterinary Research Institute.
(x) Viticultural and Oenological Research Institute.

Government Departments which support research:

(i) Department of Agricultural Credit and Land Tenure.
(ii) Department of Health.
(iii) Department of Tourism.

In addition to the above, the Administration of South West Africa also conducts research within its own laboratories and supports research undertaken on its behalf in the Republic.

(b) <u>Provincial administrations</u>

(i) Provincial Administration of the Cape of Good Hope.*
(ii) Provincial Administration of Natal.*
(iii) Provincial Administration of the Orange Free State.*
(iv) Provincial Administration of Transvaal.*

(c) <u>Statutory Councils</u>

(i) Atomic Energy Board.*
(ii) Council for Scientific and Industrial Research.*
(iii) National Institute of Metallurgy.*

The Council for Scientific and Industrial Research controls thirteen national research institutes or laboratories and a number of independent research units, and is the largest of the statutory research organizations. The laboratories and institutes falling under its control are:

Information and Research Services;
National Building Research Institute;
National Chemical Research Laboratory;
National Institute for Personnel Research;
National Institute for Defence Research;
National Institute for Road Research;
National Institute for Telecommunications Research;
National Institute for Water Research;
National Mechanical Engineering Research Institute;
National Nutrition Research Institute;*
National Physical Research Laboratory;*
National Research Institute for Mathematical Sciences;*

Republic Cbservatory;*
South African Wool Textile Research Institute;*
Timber Research Unit.*

B. HIGHER EDUCATION SECTOR

(a) Universities and university colleges

(i) Potchefstroom University for Christian Higher Education.*
(ii) Rhodes University.*
(iii) University of Cape Town.*
(iv) University of Natal.*
(v) University of Port Elizabeth.*
(vi) University of Pretoria.*
(vii) University of South Africa.*
(viii) University of Stellenbosch.*
(ix) University of the Orange Free State.*
(x) University of the Witwatersrand.*
(xi) University College, Durban.*
(xii) University College of Fort Hare.*
(xiii) University College of the North.*
(xiv) University College of Zululand.*
(xv) University College, Western Cape.*

(b) Institutes jointly supported by two or more universities

(i) Southern Universities Nuclear Institute.*

C. BUSINESS ENTERPRISE SECTOR

(a) In-house laboratories of private business enterprises

The following list is as complete as could be obtained from official sources and private enquiries, there are probably more in existence than those indicated.

(i) African Explosives and Chemical Industries Limited.*
(ii) African Oxygen Limited.*
(iii) Agricura Laboratoria Limited.*

(iv) Anglo American Corporation of South Africa Limited.*

(v) Anglo Transvaal Consolidated Investments Company Limited.*

(vi) Argus Printing and Publishing Company Limited.*

(vii) Bosal Africa (Proprietary) Limited.*

(viii) Cooper and Nephews South Africa (Proprietary) Limited.*

(ix) Cullinan Refractories Limited.*

(x) Consolidated Citrus Estates Limited.

(xi) Fisons (Proprietary) Limited.*

(xii) Hume Limited.*

(xiii) The Metal Box Company of South Africa Limited.*

(xiv) Natal Tanning Extract Company Limited.*

(xv) National Chemical Products Limited.*

(xvi) Phillips Electronics Holdings (Proprietary) Limited.*

(xvii) Plessey South Africa Limited.*

(xviii) Pretoria Portland Cement Company Limited.*

(xix) Racal-SMD Electronics (Proprietary) Limited.*

(xx) Rembrandt Tobacco Corporation Limited.*

(xxi) Seravac Laboratory (Proprietary) Limited.*

(xxii) Simon Rand Engineering (Proprietary) Limited.*

(xxiii) South African Pulp and Paper Industries Limited.*

(xxiv) R.M.B. Alloys (Proprietary) Limited/South Cross Steel Company Limited.*

(xxv) The United Tobacco Companies (South) Limited.*

(xxvi) Vereeniging Refractories Limited.*

(c) Co-operative research institutes supported by the CSIR

(i) Fishing Industry Research Institute.*

(ii) Leather Industries Research Institute.*

(iii) South African Paint Research Institute.*

(iv) Sugar Milling Research Institute.*

(d) Independent co-operative research institutes

(i) Adamant Research Laboratory.*

(ii) Diamond Research Laboratory.*

(iii) Fuel Research Institute of South Africa.*

(iv) High Pressure materials Laboratory.*

(v) South African Sugar Association Experimental Station.*
(vi) South African Chamber of Mines Laboratories.*
(vii) Wattle Research Institute.*

(e) Contract research institutes

(i) Rand Mines Laboratories.*
(ii) Gold Fields Laboratories (Proprietary) Limited.

D. PRIVATE PERSONS AND NON-PROFIT INSTITUTIONS

This category includes observatories and museums, as well as various other institutes. It also includes at least one hundred individuals and learned societies who perform research with the aid of grants provided, mainly, by the CSIR. No details are given of these. Neither are details given of the many more amateur scientists who pursue their interests without financial assistance or formal recognition.

The following is as complete a list as could be obtained:

(a) Observatories, musea and other non profit institutions

(i) South African Institute for Medical Research. *
(ii) Oceanographic Research Institute. *
(iii) Albany Museum.*
(iv) Alexander McGregor Memorial Museum. *
(v) Durban Museum and Art Gallery. *
(vi) East London Museum. *
(vii) Kaffrarian Museum. *
(viii) Natal Museum. *
(ix) National Museum (Bloemfontein). *
(x) Port Elizabeth Museum, Snake Park and Oceanarium. *
(xi) South African Museum. *
(xii) Transvaal Museum. *
(xiii) Boyden Observatory. *
(xiv) Radcliffe Observatory. *
(xv) Royal Observatory. *