THE VALUE ADDED BY PROFESSIONAL ENGINEERS TO THE ECONOMY

The Centre for Technology & Social Change

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Prepared By

The Centre for Technology and Social Change

for

The Institution of Engineers, Australia

and

The Association of Professional Engineers, Australia

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FOREWORD AND TERMS OF REFERENCE

Australia's economic recovery hinges upon our ability to create additional wealth from our natural and human resources. To this end, engineering plays a vital role in developing products for the marketplace (particularly for overseas), maintaining the national infrastructure, conserving our finite resources and protecting the environment.

Unfortunately, the role of the professional engineer has, to date, received scant acknowledgement within Australia - a situation contrasting markedly with that prevailing in more dynamic economies in the south-east Asian region.

The Institution of Engineers, Australia and the Association of Professional Engineers Australia have been concerned for some time about the low level of public awareness of the 'engineering contribution'. The two organisations therefore commissioned this study by the Centre for Technology and Social Change at the University of Wollongong, with the following terms of reference:

1. To explore means of substantiating the claim that engineers make a contribution to the economy out of proportion to their numbers.

2. To examine the national and international literature for information, analysis and approaches relevant to the key question.

3. To conduct a case study of the electricity generating industry in Australia and the contribution of engineers to its development and performance.

4. To determine whether a prima facie case supporting the significant contribution of engineers to the economy can be established and, if so, the nature and scope of further studies to amplify and substantiate the case.

Both organisations believe that the report represents a significant first step in demonstrating the value added by professional engineers to the economy.

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CHAPTER 1 EXECUTIVE SUMMARY

KEY FINDINGS

Analytical evidence of the key contribution of professional engineers to the performance of national economies is overwhelming. An extensive literature illustrates the vital importance of engineering in economic performance at the firm, industry and national level. There is also abundant evidence attesting to the costs that arise, and the opportunities that are forgone, when engineering capabilities are lacking. This evidence points to three issues that cannot be separated from an assessment of the role of engineers:

- the effective contribution of engineers is critically dependent on the overall capabilities, and on the management and organisation, of the firms and institutions in which engineers are employed;

- those countries in which engineering-related activities appear to make a particularly important contribution to economic performance are characterised not only by strong demand for engineers but also by developments in education and continuous training that have shaped the supply of engineers;

- current trends in technology and in the management of production and technological change have unavoidable and challenging implications for the role and education of future engineers.

It must be acknowledged that there are no broadly-based systematic analyses that provide a direct quantitative relationship between the activities of engineers and subsequent improvements in economic performance. However, there are good reasons for this:

- the assumptions and models underlying economic analyses of the sources of economic growth are seriously inadequate and, in particular, ignore much of the contribution of engineers;

- the sheer diversity of the role of engineers defies incorporation into the clear cut conceptual categories of economic analysis;

- the design of statistical indicators has been informed by a narrow conception of the process of economic and technical change;

- improvements in economic performance deriving, at least in some part, from the activities of engineers also involve the contribution of other personnel, expenditures and facilities. As the process of technical change is essentially interactive it is not possible to isolate the independent contribution of engineers.

Nevertheless, a number of major findings and methodological insights emerge:

- traditional approaches to conceptualising, explaining and managing economic growth, both at the micro and macro level, are based on seriously flawed assumptions regarding the process of technological and economic change. One consequence of these inadequate conceptual models is that they obscure the contribution of engineers;

- the role of engineers has also been less visible than might be the case due to the narrow formulation of the indicators used as the basis for national statistics. However, some recent approaches provide a framework for widening the coverage of technological activities. These broader approaches would contribute to a greater awareness and more adequate understanding of the contribution of engineers (and others) to economic performance;

- outside the literature of conventional economic analysis a diverse range of studies provide partial insights into the contributions of engineers. Studies that examine the processes of performance improvement in firms, or that seek to explain differences in competitiveness at the firm or industry level, frequently highlight the role of engineers and engineering activities;

- studies in economic history or the history of technology provide rich illustrations of the critical role of engineering. Particularly significant are the studies of countries at the early stages of industrialisation when the existence of engineering capabilities could not be taken for granted, and the lack of such capabilities was a key constraint on economic growth. In many cases this constraint provided the impetus for social innovations to enable the supply of engineers through public sector and within-firm training;

- nevertheless, for both conceptual and methodological reasons there is little prospect that conventional economic growth accounting or cost/benefit analyses could meaningfully estimate the contribution of engineers to value-added or other measures of economic performance;

- there has been considerable recent work to develop a conceptual framework capable of bridging the wide gap between economic theory and empirical analyses of economic and technological change. These new approaches emphasise that:

- continuous incremental improvements in products, processes, and organisation, are as important a source of productivity improvement as are major innovations and investment in new facilities;

- the cumulative development of technological capabilities within firms is a vital source of competitiveness;

- relationships between firms (for example, between customers and suppliers) involving the communication and transfer of technical information and knowledge is an essential aspect of effective innovation and engineers have a central role in these networks;

- managerial and organisational change within firms, and social innovation in organisations involved in education and research, have had a vital role in the effective development, management and application of technical knowledge;

- the supply/demand dynamics for new knowledge and technology-related human resources cannot usefully be analysed outside the context of the national institutions and relationships that influence the generation, diffusion and application of technology. These institutions and relationships develop through an historical evolution involving continuous interaction between supply and demand;

- these studies, and the perspectives they develop regarding the process of technological and economic development, are of considerable significance for the training and career development of engineers. In addition, an increasing number of recent studies assemble evidence and argument which provides a convincing case for the view that a new phase of industrial change is unfolding. This will involve new approaches both to the technology, management and organisation of industrial production and to the management of technological change. These trends have far-reaching implications for engineers. They bring challenges for engineers to re-define their roles, and considerable new opportunities if they do so.

An international comparative perspective on engineering employment in Australia provides strong evidence that engineering activity in Australia is low by OECD standards:

- engineers constitute a significantly lower proportion of the population and work force in Australia;

- engineers account for a substantially lower proportion of the Australian manufacturing industry work force;

- a relatively low proportion of engineers in Australia are involved in R&D;

- a good deal of less systematic evidence also suggests that the contribution of engineers is afforded greater recognition in those countries where engineering activity and economic growth is higher.

But these qualitative and quantitative comparisons must be interpreted carefully. The relationships between supply and demand for engineers are complex and linked to wider processes of education, training and corporate behaviour, which vary considerably between countries. These supply/demand and wider relationships have evolved (and continue to do so) within the context of 'national production and innovation systems'.

In the current phase of structural and cultural change in Australia the questions and challenges raised by these issues take on particular significance and urgency. The attitudes and relationships inherited from past history, rather than the priorities of the present or the opportunities of the future, are likely to continue to influence broad community views regarding the status of engineers, employers' attitudes regarding the value of investment in technology in general and the contribution of engineers in particular, and the attitudes and perspectives that guide the career paths and education of engineers.

The survey suggests that further work could make a valuable contribution by:

- increasing the awareness of policy-makers regarding the vital role of engineering in increasing national competitiveness in general, and value-adding in particular;

- increasing the awareness of industrial managers regarding the contribution that investment in engineering can make to economic performance, and illustrating how successful firms are exploiting the potential of engineering;

- improving the image of engineering as a career by increasing awareness of the career paths open to engineers, the changing role of engineers and the increasing requirements for engineers in Australian industry;

- developing a well-informed assessment of the changing roles of engineers and identifying the implications of these trends for career development, education and training;

- widening the scope of national statistics to increase the coverage of engineering-related activities in order to both raise the visibility of engineering and better inform policy research and policy development.

The recommended studies are:

1. Raising the Competitiveness of Australian industry - the Role of Engineering

The primary objectives of this study are:

- to develop a coherent theoretical framework as a basis for assessing the contribution of engineers;

- to assemble a considerable body of systematic evidence that demonstrates the relationship between the 'engineering dimension' and various types of economic performance - particularly those aspects of performance most relevant to Australia;

- to identify and characterise those capacities and activites that constitute the 'engineering dimension';

- to analyse, and draw out the implications of current developments that are fundamentally changing the 'engineering dimension' of production and innovation.

2. Statistical Analyses of 'Engineering Intensity' and of Technology Inputs and Economic Performance in Australian Industry

- *Industry specific comparisons of 'engineering intensity'*
  It appears that 'engineering intensity' (employment of engineers in relation to value-added) varies more widely between different industry sectors in the same country than in the same industry in different countries. This study would develop international inter-industry comparisons of 'engineering intensity'.

- *Time series and inter-industry analyses of technology-related inputs and economic performance in Australian industry*
  Analyses which bring together data on engineering employment, capital investment, R&D expenditure and other technology-related input indicators, and

related these to such economic output indicators as value-added, productivity and exporting may provide statistical support for a relationship between engineering activity and economic performance.

3. Engineers in Leading Australian Firms

The objective of this project would be to develop a series of case-studies of change which provide detailed evidence of the contribution of engineers in Australian industry. Case study firms could be selected from 'leading edge' firms who were recipients of Export Awards and Engineering Excellence Awards and firms participating significantly in such NIES programs as World Competitive Manufacturing (WCM).

The study would also provide a basis for analysing the development and careers of engineers within industry. Information from the case studies could also be combined with a wider review to develop a detailed assessment of the changing role of the engineer - and the opportunities these changes open for the profession.

4. Engineers and Economic Performance in the Electricity Supply Industry

Our preliminary review noted the changing management priorities in the electricity supply industry (ESI). These changes raise challenges and opportunities for engineers and will require a 're-positioning' of engineers in the future ESI. To a significant extent this re-orientation in the ESI parallels developments in other utilities.

There is a case for studies to more clearly identify the contributions of engineers in the ESI and to assist the re-positioning of engineers. The objectives of such studies would be:

- to specify a range of indicators of performance of the ESI and assemble international comparative performance data;

- to identify the direct and indirect contribution of engineers to the sources of improved performance and identify the types of technological capabilities that it will be essential to maintain for continued performance improvement;

- to identify the institutional structures, managerial approaches and other factors that have facilitated or hindered the contribution of engineers;

- to identify the key contributions of engineers to the current priorities of the ESI and analyse the arrangements (e.g. organisation, management, training) that will strengthen the effectiveness of the role of engineers.

5. Engineering Consultancy Exports and Their Contribution to Australian Merchandise Exports.

Exports of engineering services can be a significant source of income and there are undoubtedly opportunities to expand such exports, particularly to Asian markets. Information in this report on United States exports of technical and engineering services indicates that such exports can also facilitate substantial merchandise exports.

This study would survey the development of Australian engineering exports and assemble evidence regarding the role of these exports in facilitating Australian merchandise exports.

CHAPTER 2 INTRODUCTION

> Engineers have an importance in society out of all proportion to their numbers. They draw on the engineering sciences, which are based mainly on physics and chemistry, to establish opportunities to introduce new or improved products and processes of production and so lift levels of technology. Their role is so important in economic growth that in the last few years many countries have appointed committees of inquiry to investigate both the quality and quantity of engineering education.[1]

So reads the second paragraph of the Conclusion and Recommendations of the 'Review of the Discipline of Engineering' chaired by Sir Bruce Williams.

This argument provides the genesis of this present report and is also taken up as the theme of the Engineering Task Group report to the Warren Centre project on Future Directions in Engineering.[2]

Assertions of the special role of the engineer are to be found in many reports and articles. Elsewhere in the Williams Report, it is stated that:

> The distinctive branches of the engineering profession - aeronautical, chemical, civil, electrical and electronic, mechanical, mining and industrial - are an indication of the great range of the skills and activities of engineers. They play a very important part in raising productivity and real incomes. They make or facilitate frequent incremental improvements in product and processes, they aid the transfer and adaptation of state-of-the-art technology from abroad, they participate in the design and development stages of indigenous research and development and the transfer and scaling up of laboratory or workshop models to commercial production scales, and they help in establishing an effective production system around new plant and equipment.[3]

The Warren Centre Report sees the challenge of making Australian industry more internationally competitive improving the conceptual, creative and technical skills of the labour force and the ability to innovate as a challenge to engineering: 'Clearly, of all tertiary education disciplines, engineering must be seen as central to ... this concern'.[4]

In a similar view, Edelstein notes:

> In hundreds of professional handbooks, graduation speeches, introductions to university calendars, and inscriptions adorning university buildings, engineering is described as the art of directing the great sources of power in nature for the use and convenience of man, or words to similar effect. Engineers, it would appear, are among the central figures in modern economic growth, for their essential vocation is the application of science to problems of economic production.[5]

The last quote exemplifies a common view of the role of engineers, and raises some of the difficulties in assessing the nature and extent of their contribution. If engineers are among the

1 'Review of the Discipline of Engineering', (the Williams Report), AGPS, Canberra, 1988, Vol. 1, pi. x.

2 'Preparing Australians for a Future with Technology', The Warren Centre, University of Sydney, 1988, p. 57.

3 Williams Report, op. cit., p. 2.

4 Warren Centre Report, op. cit., p. 63.

5 M. Edelstein, 'Professional Engineers in the Australian Economy, 1866-1980', Working Paper in Economic History, No. 93, ANU, 1987, p. 1.

central figures in modern economic growth, and if they do play an essential role in the application of science to problems of economic production either directly or via application of engineering, now recognised as one of the most significant factors in international economic competitiveness, then their place and the extent of their contribution, is assured. All that is required is to prepare the citations, and the arenas for triumphal celebration.

But defining engineers as central to economic growth does not ensure that this is actually the case, still less that this will be broadly perceived. A number of interesting questions arise:

- what is the extent of the contribution of engineers to the economy, both absolutely and relatively?
- the arena for the 'application of science to the problems of economic production' is quite densely populated, and highly contested; how much of the credit can engineers claim, as against scientists, managers, marketers, advertisers, consultants and accountants (some of whom may of course have engineering qualifications)?
- do engineers have a special role as the creators of opportunities for capital, or are they primarily servants of the interests of capital?

An interesting and important attempt to grapple with the special nature and role of engineers and to improve the public standing of engineers and at the same time their contribution to a national economy was provided by the UK Report of the Committee of Inquiry into the Engineering Profession, known as the Finniston Report.[6]

The Terms of Reference of this Inquiry related to the role and contribution of engineers and engineering in promoting the efficiency and competitiveness of the country's manufacturing performance. In order to address this issue, the concept of the 'engineering dimension' was developed. This dimension encompasses:

> the effectiveness of manufacturing organisations in translating engineering expertise into the production and marketing of competitive products through efficient production processes.[7]

The Report noted:

> While the contribution of engineers to the engineering dimension is obviously central, and thus of critical moment for the future of British industry, attention to the numbers, qualities or organisation of engineers alone will not resolve the country's present economic situation. What is required is greater national acceptance, as is to be found in our more successful industrial competitors, of the importance to employment and prosperity of successful market-oriented, engineering-based manufacturing industries, and the mobilisation to this common purpose of supporting attitudes and policies among

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6 **Engineering Our Future**, Report of the Committee of Inquiry into the Engineering Profession, (Finniston Report), HMSO, London, Cmnd.7794, 1980.

7 Finniston Report, **op. cit.**, p. 3.

> the whole range of functions and disciplines - engineering and non-engineering alike - which together determine the performance of manufacturing industry.[8]

On the basis of their collective experience, and extensive submissions, and overseas visits, the Report was able to claim:

> Among those manufacturers in this country and overseas who have prospered in world markets, we found a common characteristic in the way they had built upon excellent engineering, integrated into enterprising and forward-looking market and product strategies. Managements in these companies clearly regarded engineering as the common factor linking the inputs of the various specialist functions within the organisation to its overall objectives. Engineers were involved in each stage of the manufacturing process, from the technical appraisal of world market opportunities and the translation of those appraisals to the design of products and systems to exploit the opportunities through to the development, manufacture, sale, delivery and service marketing, design, research, manufacturing and selling, with all concerned seeking to ensure that the company's products met the demand of world markets.
>
> The engineering performance of manufacturing enterprises depends not only upon the numbers and qualities of engineers employed but equally if not more, on the effective priority accorded to engineering in the enterprise, and on *the capability of the organisation as a system for translating engineering expertise into the production and marketing of competitive products through efficient production processes.*[9]

On this subject the Report concluded:

> While engineering excellence is not the only determinant of manufacturing prosperity, the example of the most successful companies shows that it is *essential* to continuing competitiveness. That excellence derives from the effective priority accorded to engineering in manufacturing enterprise, and the capability of the organisation as a system for translating engineering expertise into the efficient production and marketing of competitive products, which capability depends upon companies' understanding and development of the 'engineering dimension'.[10]

An emphasis on the importance of the role for engineers in the increasingly internationally competitive market-place was identified:

> The opportunities afforded by recent technological achievements present rich markets to companies with the market perceptions and engineering capabilities to exploit them. ...the central, critical and growing place of engineering and engineers within *any* scenario is illustrated by considering emerging developments in:
>
> - the availability and real cost of *basic resources*;
> - the evaluation and impact of *new technologies*;
> - the intensification of *competition* between industrial nations;
> - the economic impact of *social and political trends*.[11]

A number of highly significant special roles were identified for engineers. Thus, Finniston supported the findings of studies of the process of innovation that, in the majority of cases an individual product champion, 'almost always an engineer',[12] provided the motive force for

8 Ibid.
9 Ibid, p. 22.
10 Ibid, p. 23.
11 Ibid, pp. 18-19.
12 Ibid, p. 37.

success. In addition, engineers must be concerned not only with technically optimal solutions but with human and organisational factors, because:

> whether in new projects where fundamental changes in the organisation of work are to be made, or in seeking operational improvements to existing systems, [the work of engineering] has direct and indirect effects on the tasks of other workers in the enterprise, and the total organisation of work.[13]

The Finniston Report concludes by identifying a critical and new role for engineers:

> The industrial society of the future has to adapt not just to the consequences of past changes but also to the enhanced rate of change which new technology and its adoption throughout the world are creating and will continue to create as long as can be foreseen; micro-processors are just one example of future shock. In the introduction and management of these changes the main thrust lies in the area of engineering. Without highly educated and trained engineers, continually updating their skills and given authority and influence in concert with other industrially-biased disciplines to implement the products of those skills, there can be no confident prospect of stemming.[14]

In assessing the arguments in the Finniston Report, it is appropriate to direct attention to the central concept of the 'engineering dimension'. For, while the central economic significance of the ability to translate knowledge into market-oriented products is widely acknowledged, labelling this as 'the engineering dimension' serves only to obfuscate the particular role of the engineer, and to reduce the extent of their contribution to a tautology.

If the interaction of knowledge and production is described as the 'engineering dimension', the important question becomes 'what is the contribution of engineers to the engineering dimension?'.

Another important insight on this question is provided by the Finniston Report's extensive comparison of the UK situation with that of other countries. It was concluded that in many of these countries the engineering profession had higher status and rewards, engineers made a greater and more direct contribution to the performance of a firm, and more engineers entered senior management roles. This relationship was also noted in a recent OECD study:

> Apart from the questions concerning the context and organisation of training, the quantitative and qualitative match between scientific and technical personnel supply and demand depends a great deal on the professional and social status of the researcher, engineer and technician trades. If the engineer is regarded as less 'noble' than the financier ... it is very probable that there will be a permanent shortage of the high quality scientific and technical personnel who are needed to translate scientific and technical progress into technical change.[15]

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13 Ibid, p. 40.
14 Ibid, p. 158.
15 OECD, **The Contribution of Science and Technology to Economic Growth**, CSTP, OECD, Paris, 1989, p. 124-25.

The point of interest is not why or how countries differ, but the fact that they do. This clearly demonstrates that the contribution of engineers to a national economy is not a matter of scientific (or even economic) law. The place of engineering and the extent of the contribution to an economy is culturally determined, a product of industrial structure, trade experience and work organisation and attitudes.

Within this perspective, the appropriate question is no longer, 'what is the contribution of engineers to the economy?', but rather 'how can the capabilities of the engineering profession be most effectively interlinked with productive activity in order to achieve economic and social goals?'. Such a change has occurred in the UK in the decade since the Finniston Report, with a shift in emphasis from the relationship of engineers with economic performance, to analyses of factors affecting the demand for engineers, the requirements of training, and influence of policy.

In an era when the generation and exploitation of knowledge, both theoretical and experiential, is central to economic performance, **and** there is a growing range of competing expertise to pursue this objective, what is the **special** role of the engineer? Secondly, how can the effectiveness of this role be increased?

CHAPTER 3 INTERNATIONAL COMPARISONS

3.1 THE NUMBER OF ENGINEERS ACTIVE IN THE ECONOMY

The number of engineers employed in professional engineering or engineering management positions by a country is a significant indicator of technologically-oriented economic activity. The number can be measured against population size, or numbers in the workforce to give a value of 'engineering intensity' of the country. Table 3.1 shows the number of engineers per 100,000 population in several countries.

Table 3.1 Engineers Relative to Population by Country

Country	Year	No. Engineers per 100,000 Population	Ratio (Australia in 1985 = 100)
United States	1984	777	198
Japan	1984 1975	660 422	168 107
Canada	1983	528	134
Sweden	1983	477	121
Australia	1989 1985	473-559 (See text) 393	120-142 100

Source: Rice and Lloyd, (1990), amended by TASC.

If the figure of just under 400 Australian engineers per 100,000 in 1985 is used, we have an 'engineering intensity' which is half that of the United States and 60 per cent that of Japan. It is noteworthy that the number of engineers per 100,000 population in Japan grew by 56 per cent between 1975 and 1984 (a 4.4 per cent growth rate) from a position in 1975 similar to Australia's in 1985.[16]

Our engineering intensity can therefore be characterised as being at least 15 years behind that of Japan, and about six years behind Canada and Sweden.

Rice and Lloyd (1990) estimated the engineering labour force in Australia to be 55,674 in 1976, 72,529 in 1983; and 92,279 in 1989. This represents a 3.8 per cent growth rate between 1976 and 1983, and 4.0 per cent between 1983 and 1989, indicating almost constant growth over the period. Assuming that Japan maintained its rate of growth as a proportion of the population, it would have 892 engineers per 100,000 population in 1989, compared with Australia's 559 (using an Australian population figure of 16.5 million).

[16] National Science Foundation, **Science Indicators**, Washington, 1985. Note that the figure for engineers per 100,000 population given in this publication has been discounted by 18 per cent for Table 3.1, to include only professional engineers.