THE EFFECTS OF CHANGES IN RECYCLING PATTERNS ON UNITED KINGDOM RESOURCE CONSUMPTION

by

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A Thesis submitted to
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for the Degree of Doctor of Philosophy

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University of Aston in Birmingham.

November, 1981

The Effects of Changes in Recycling Patterns on United Kingdom Resource Consumption

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Summary

Recycling, substitution and product life extension are identified as significant factors contributing to an extension of the time to exhaustion of industrially important materials.

A quantitative assessment of the significance of virtually all materials to the U.K. is made. Copper is identified as one of the most important materials deserving of further investigation into potential resource savings through increased recycling. The other factors listed above are accounted for in the modelling technique employed.

United Kingdom copper flows are qualitatively and statistically described for the years 1949 - 1976. Less accurate statistics are developed for 1922 - 1948.

Adaptive expectations type causal models of total, unalloyed, and alloyed copper demand are successfully constructed and are used to generate future scenarios. Evidence is demonstrated for a break in the historical link between U.K. copper demand and industrial production.

Simple causal models of potential copper scrap supply are constructed and a comparison made with actual old scrap withdrawals. Accurate adaptive expectations type models of total scrap demand are developed, but no conclusion is reached about the price elasticity of scrap demand.

Various scenarios of copper goods demand are forecast and their effec on copper scrap demand. The potential to recover up to an extra 100 000 tonnes/year of generally lower grade old scrap is identified.

Policy options are examined and the following recommendations made:

1) A total investment of up to £67 million in secondary refining capacity by the year 2000 is needed.
2) The copper scrap content of copper bearing goods should be specified to aid recovery.
3) A U.K. copper scrap buffer stock scheme would be advantageous for the secondary copper industry.

Finally the methodology used is summarised for potential application to other materials.

Key Words

Copper; Recycling; Scrap; Modelling; Policies.

This thesis is dedicated to my father - whose help and
encouragement provided the incentive for this work,
but who unfortunately was unable to see the fruit of
the seed he had sown

ACKNOWLEDGEMENTS

The author is indebted to and wishes to record his gratitude to the following people.

Dr. A.V. Bridgwater for his valued guidance and personal interest throughout this work.

Dr. E.L. Smith for his helpful advice.

Mr. G.A. Bone and Mr. W.D. Graham of B.P. Oil Ltd. for their assistance in the completion of this work.

My wife, mother and family for their unfailing moral support.

LIST OF CONTENTS

Page No.

Page No.

CHAPTER 4 - THE STRUCTURE OF THE U.K. COPPER INDUSTRY 103

Page No.

LIST OF TABLES

Page No.

Page No.

LIST OF FIGURES

Page No.

Page No.

Page No.

CHAPTER 1 - INTRODUCTION

The publication of "The Limits to Growth" in 1972 (1) re-emphasised previous comments on the potentially catastrophic results of a continuing exponential growth in the use of limited mineral resources. What made this work different was the computing power used to model global issues - a previously unrealistic task. While the arguments on the validity of the assumptions used and conclusions reached continue, the Meadows model achieved its purpose; to direct attention to the possible results of an increasing standard of living and/or population.

Additionally, the Yom Kippur War of 1973 revealed the dependence of developed countries upon imports of strategically important materials. Potential geographical instability prompted other workers to improve on the "Limits to Growth" model by disaggregation into sub-global systems and investigating the flows between these systems. At national level, governments have started to investigate the future supply of strategically important materials. In industry, successive world and national economic recessions coupled with rising raw material costs in real terms have prompted both the more efficient utilisation and the use of alternative materials.

The exploitation of recycled materials satisfies many of the problems outlined above and, as well as contributing to national interests, benefits may arise such as lower import bills, better Balance of Payments figures, increased employment, reduced energy consumption and a more stable source of supply. Counter-balancing these benefits are, for example, the social and political problems resulting from reduced virgin production in developing countries.

The United Kingdom (UK) is a prime example of a nation which lacks some essential indigenous raw materials and so relies heavily upon imports of raw materials essential to its future as a trading nation. For this reason, the UK is particularly affected by international affairs beyond its control, making economic planning difficult. This was particularly true with respect to oil supplies before the discovery of North Sea Oil. If the UK can become less reliant upon imported raw materials and more dependent upon indigenous supplies, and in particular recycled materials, then a tangible benefit upon the economic performance of the UK could arise.

Unfortunately the overall aims of government towards resource management do not always concur with the views of industry. In particular, there is believed to be a view by industry that consumers view some secondary materials as second rate and industry is therefore concerned that a change towards recycled products will affect demand. Additionally, certain policies, such as decreasing imports of raw materials by extending the useful lifetime of fabricated goods, are contrary to the planned obsolescence approach adopted by some industrial sectors.

This project aims to examine the potential for reduced UK consumption of primary resources and to identify the effects of any such reduction on the UK economy and industry. Policy tools available for achieving this potential will be examined and recommendations made.

The methodology adopted in this project is not entirely a conventional economic analysis but, instead, reflects an engineering approach in the form of a classical mass-balance accounting system examining inputs, outputs and accumulation. This is supplemented, where appropriate, by economic analysis to model selected flows centering around the potential supply and demand for recycled material.

In the first part of the project, the evidence for concern over the time to exhaustion of a range of materials is examined and alternatives to continuing exponential growth examined. These alternatives include recycling and the advantages and disadvantages of this alternative are presented. A method of assessing the significance of materials to the UK using a series of weighted selected criteria is then developed and copper is selected as a prime candidate for further investigation. UK copper flows are examined and statistically defined. Deficiencies in available statistics on these flows and the structure of the UK copper industry are identified before discussing the end-uses of copper. The annual statistics on copper flows are used to provide both a "snapshot" in any one year, and to examine trends in one or more flows over a number of years.

In the second part of the project, a modelling technique is selected to model selected UK copper flows. An examination of copper prices shows that modelling of this particular variable is beyond the scope of this project. Successful models of total, unalloyed and alloyed demand are constructed. The flow of copper goods after their useful life is examined and a comparison made of scrap supply and demand. The destination of unrecovered scrap is studied for increased recovery potential.

Scrap demand is modelled before forecasts of future scrap supply and demand are made, the potential for increased recovery identified and the necessary investment required to realise this potential estimated. The policy options available to promote the use of the potentially recoverable copper scrap are examined and recommendations made.

Finally, the methodology developed in this work is summarised so that its application to other materials is possible.

CHAPTER 2 - THE SIGNIFICANCE AND OPPORTUNITIES FOR RESOURCE CONSERVATION

2.1 Introduction

The recurring controversy about the adequacy of natural resources to supply future needs was accentuated by the publication in 1972 of "The Limits to Growth" (1) and "Blueprint for Survival" (2). The pessimistic view is that at the present rate of consumption many important resources will be exhausted within approximately fifty years, i.e. within one generation, so raising immediate concern. The optimistic view is that there is no need for concern by this or the next generation, i.e. there will be no significant exhaustion of resources in the next hundred years.

Historically the optimistic view has been justified, mainly because the rate of consumption of mineral reserves has been relatively small compared to total reserves. However, since the Second World War consumption and, more importantly, the rate of increase in consumption have risen dramatically, even to the extent that it has been estimated that more mineral reserves have been used in the United States since the Second World War than in the entirety of previous history.

The current disagreement over the adequacy of mineral resources revolves around the validity of the estimates of the absolute supply of available resources and the time to exhaustion of these resources. This chapter examines the definition of resources and reserves without dwelling upon the problems of their measurement, as this is beyond the scope of this project, and goes on to examine various means of assessing their ability to supply in future years. Definitions are then given for the various material flows through an economy followed by a discussion on the advantages and disadvantages of recycling and the need and mechanisms of obtaining the socially optimum recycle ratio. Finally, the alternatives to recycling and the possibility of non-exponential growth are examined.

A discrete literature review is not included as, by the nature of the project, relevant references are included where appropriate through the dissertation.

2.2 Reserves, Resources and Life Indexes

2.2.1 Definition of Reserves and Resources

In 1961, the U.S. National Resources Committee defined a natural resource as any naturally occurring element, product or force that can be used by man in his contemporary environment (3). Such a definition includes renewable and non-renewable resources. Non-renewable resources are materials that have been built up or evolved on a geological time scale and cannot be replaced except over a similar time period. Although not included in the National Resources Committee, definition, non-renewable resources may also be broken down into those that in normal use remain fundamentally unchanged, (such as copper or iron used in motor vehicles) and so are always potentially available for recycling, and those that are altered during use in such a way as to make them unamenable to recycling. Examples of the latter include fuels where the combustion products are irretrievably lost. This breakdown will be discussed in more detail in Section 2.2.4. Renewable resources are defined by the National Resources Committee as those that may be renewed within a geologically short period, normally from solar energy e.g. trees, livestock and wind and waves.

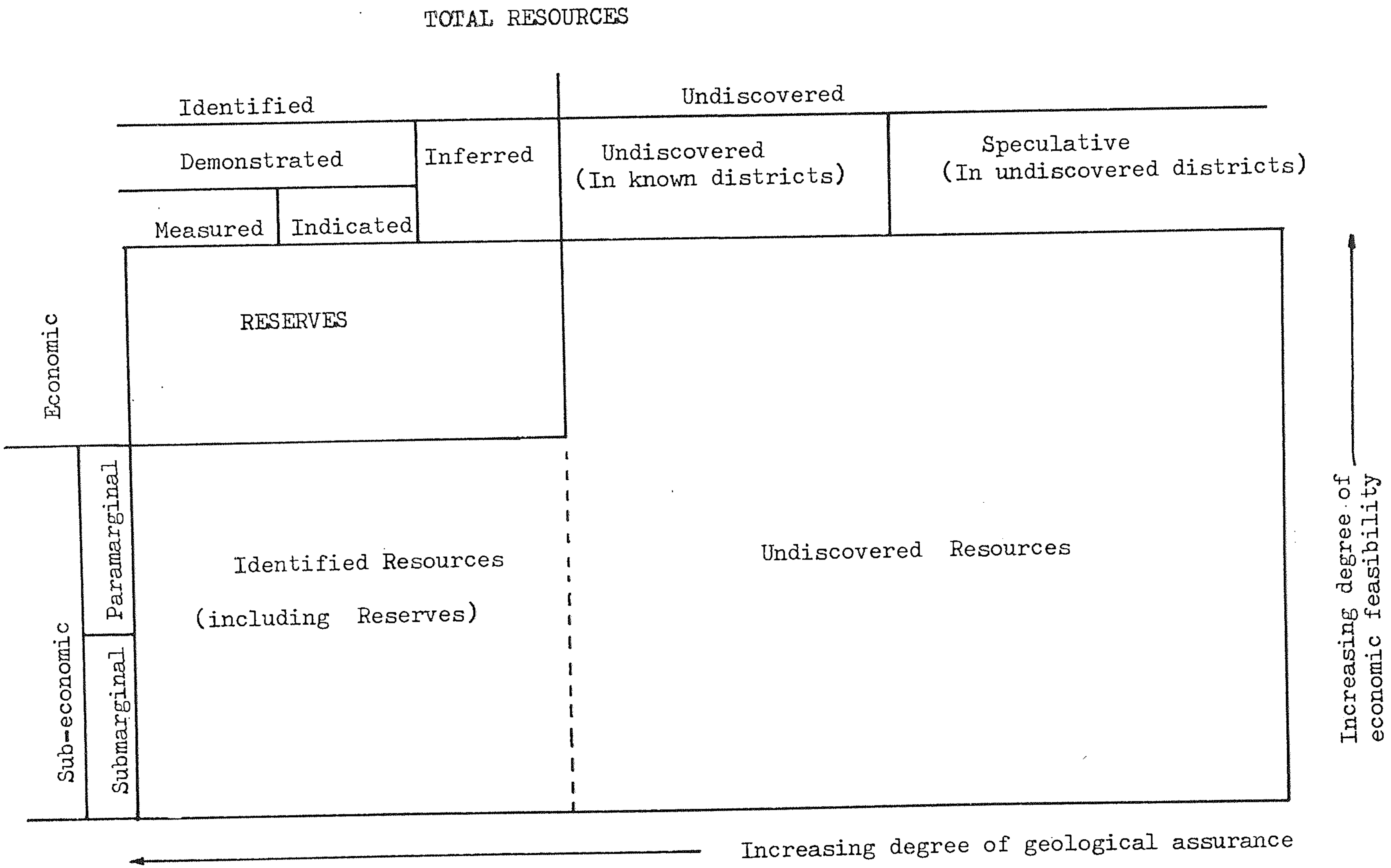


Figure 2.1 $M^cKelvey$'s Classification of Resources (4)

The definition and graphical representation of reserves and resources is complex and a basic outline only will be given here without dwelling upon the methods of their assessment.

McKelvey (4) developed previous work by Blondel and Laskey (5) to form a classification system which has been adopted by the U.S. Bureau of Mines (USBM) and the U.S. Geological Survey and is shown in Figure 2.1. The abscissa and ordinate provide the framework for the classification and represent the two principle variables, namely the quality and magnitude of resources and the relationship of the two variables shows the feasibility of their recovery.

Using McKelvey's system, the definitions in Table 2.1 and Table 2.2 refer to the geologic and economic axes of Figure 2.1.

Using these definitions it is now possible to define amongst others, reserves and resources as given in Table 2.3.

The McKelvey classification may be simplified by considering only the relationship between price and quantity available for extraction as exemplified for Uranium in Figure 2.2. Price affects the quantity available for extraction by either making a currently uneconomic process viable or by making low grade material economic to extract (As a point of interest, for uranium, an increase in price by a factor of ten increases reserves by about the same factor, although this is not so for all minerals). More importantly, the reserve size provides a lead-time for further reserve increases either by new discoveries or technological progress. If reserves are not added to in this lead time, rising prices due to shortfalls in supply will make previously sub-economic reserves economic. Enormous price rises would be necesary before all resources became economic.

Table 2.1 - Definitions Relevant to the Geologic Axes of Figure 2.1

1.	Measured Resources :	Material for which estimates of quality and quantity are available to within 20%.
2.	Indicated Resources :	Material for which estimates of quality and quantity have been computed from samples and reasonable geologic projections.
3.	Demonstrated Resources : 1+2	Measured resources + indicated resources.
4.	Inferred Resources :	Materials in unexplored but identified deposits for which estimates of quality and quantity are based on geologic evidence and projection.
5.	Identified Resources : 1+2+4	Demonstrated + inferred resources.
6.	Hypothetical Resources :	Undiscovered material in known mining areas. Exploration confirming their existence will allow their reclassification.
7.	Speculative Resources :	As hypothetical resources but in areas where no discoveries have been made.
8.	Undiscovered Resources : 6+7	Hypothetical + speculative resources.
9.	Total Resources : 5+8 (or 1+2+4+6+7)	Identified + undiscovered resources.

Table 2.2 - Definitions Relevant to the Economic Axis of Figure 2.1

1.	Economic :	Resources which are currently economic to extract.
2.	Paramarginal :	Resources which border on being economic or which are not available because of legal or political circumstances.
3.	Submarginal :	Resources which would require at least a 50% increase or a major cost reducing advance in technology before extraction become paramarginal or economic.
4.	Sub-economic : 2+3	Paramarginal + submarginal.

Table 2.3 - Definitions of Reserves and Resources using Figure 2.1

a.	Resource : b+c	A concentration of naturally occurring solid, liquid or gaseous material in or on the earths crust in such form that economic extraction is currently or potentially feasible.
b.	Identified Resources :	Specific bodies of material whose location, quality and quantity are known from geologic evidence supported by engineering measurements with respect to the demonstrated category.
c.	Undiscovered Resources :	Unspecified bodies of material surmised to exist from broad geologic knowledge and theory.
d.	Reserve : d b c	The portion of an identified resource from which a usable commodity can be economically and legally extracted at the time of determination.

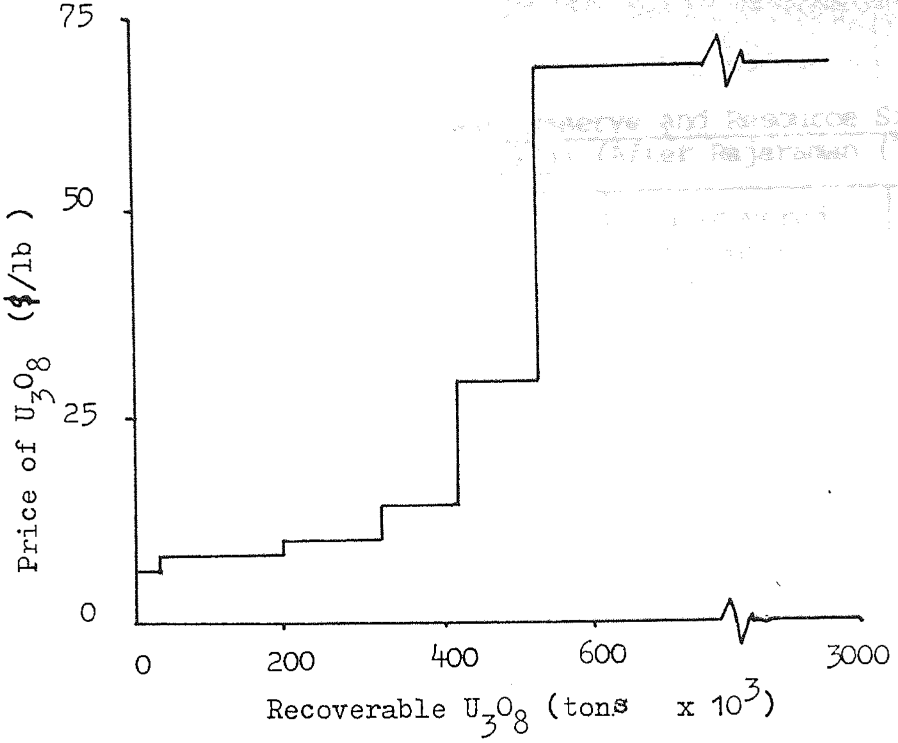


Figure 2.2 - Availability of Uranium at Different Price Levels (6)

2.2.2 Reserve and Resource Estimates for Various Materials

The quantity and quality of reserves and resources are continually changing as material is extracted, new discoveries made and price changes occur and as a result any estimates of reserve and resource size are dependent upon the time of their estimation. The definition of reserve size given in Section 2.2.1 includes a twenty per cent error margin and the definition of a resource precludes any accurate measurement. These factors together with limitations on available data, the effect of price changes, new discoveries and technical developments, produce continual changes in the physical estimates of reserve and resource size.

Rajaraman (5) presented 1973 data on the size of some of the reserve and resources defined in Section 2.2.1. These data are given in Table 2.4 as a function of reserve size.

Table 2.4 - Relationship Between Reserve and Resource Size for Various Materials (1973) (After Rajaraman (7))

Material	Sub-economic resources / Reserve size(a)	Identified resources / Reserve size(b)	Undiscovered resources / Reserve size(c)	Total resource / Reserve size(d)
Aluminium	n.a.(e)	n.a.(e)	n.a.(e)	Very large
Chromium	1.61	2.61	2.16	4.77
Cobalt	0.67	1.67	n.a.(e)	n.a.(e)
Copper	1.63	2.03	1.95	3.98
Iron	1.60	2.60	n.a.(e)	n.a.(e)
Lead	10.42	11.42	1.46	12.88
Manganese	1.19	2.19	1.53	3.72
Molybdenum	5.70	6.70	234.04(f)	240.74(f)
Nickel	0.52	1.52	n.a.(e)	n.a.(e)
Tin	3.77	4.77	4.00	8.77
Zinc	11.71	12.71	30.08	42.79

Notes to Table 2.4

(a) Ratio of → sub-economic resource size to reserve size. To be re-classified as reserves a real price increase would be necessary.

(b) Ratio of reserve size to identified resource size. Includes both reserves and sub-economic resources.

(c) Ratio of reserve size to undiscovered resource size. Includes both hypothetical and speculative resources (approximate values only)

(d) Ratio of reserve size to total resource size. Total resource size includes identified and unidentified resources (approximate values only)

(e) n.a. = not available.

(f) Does not include speculative resources.

In the short term the ratios of sub-economic and identified resources to reserve size are important when considering potential material supplies and these resources could, with a price and technology change become reserves. The other ratios given for undiscovered and total resources reflect the long term potential supply of the materials concerned assuming dramatic changes in price and technology. Table 2.4 shows that identified resources are normally double the reserve size for those materials listed, with the exception of lead, molybdenum, tin and zinc where ratios of 11, 7, 5 and 13 respectively occur. In the case of molybdenum and zinc very large undiscovered resources are predicted indicating that deposits may be readily discovered (possibly as a result of exploration for other minerals) which will increase the identified resource figure. A similar argument may be applied to the discovery of lead deposits where they are in association with other, more precious materials e.g. copper.

While reserve:resource ratios are useful tools for assessing potential resource size they ignore the role of technology and economics in determining mineral supplies. It may be argued that there were no uranium reserves one hundred years ago since uranium was not a known economically useful mineral, but clearly uranium has always been a resource; only reserves of uranium have increased. Germanium was identified in 1886 but there was no demand for it until the transistor was developed in the 1940's. Aluminium, beryllium, cadmium, columbium, magnesium, tantalum, titanium, tungsten, uranium, vanadium and zirconium have all come into use in industry only in this century (8). While the degree of exploration success and technical factors determine the size of reserves and the reserve to resource ratio, the only hypothetical upper limit which may be placed upon resource size is governed by the crustal abundance of the material in question.

2.2.3 Crustal Abundance, Reserves and Resources

In 1960 McKelvey (9) showed that there is a fairly close relationship between reserves in the U.S. and the crustal abundance of materials in the Earth's crust; Sekine (10) showed that the same relationship held in Japan and not unexpectedly Govett and Govett (11) demonstrated that the relationship is also true on a global basis.

The relationship between world reserves and the crustal abundance is shown for sixteen common metals in Figure 2.3.

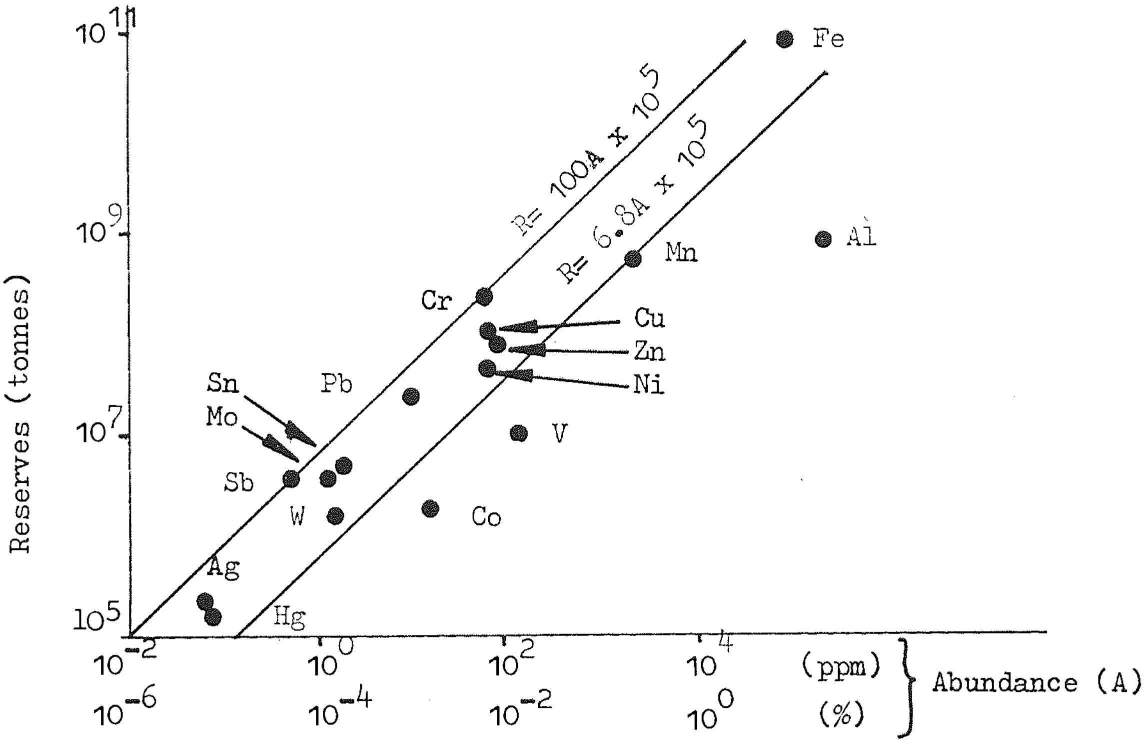


Figure 2.3 Relation between world reserves and continental crustal abundance for sixteen common elements (11)

All industrially important elements, with the exception of aluminium, cobalt and vanadium fall into the band

$$R = 6.8A \times 10^5 \text{ to } R = 100A \times 10^5$$

where R = reserves in tonnes and A = average abundance in the continental crust in ppm. This is a spread of approximately one order of magnitude. For the materials that fall outside this range the following arguments may apply. In the case of aluminium the large amount of aluminium in clay materials which are not presently regarded as reserves would bring it up to the lower limit of the relationship. Cobalt and Vanadium are largely by-product metals of other ores.

The above correlation might be expected, but for the correlation to be useful it is necessary to determine a reasonable upper limit for the correlation constant. Figure 2.4 shows reserves of lead, copper, zinc, chromium, manganese and iron for 1948, 1965 and 1970. Lead, copper and iron show an increase over the whole period while manganese, chromium and zinc show fluctuations. For zinc, reserves were stationary from 1965 to 1970 while manganese and chromium show definite decreases.

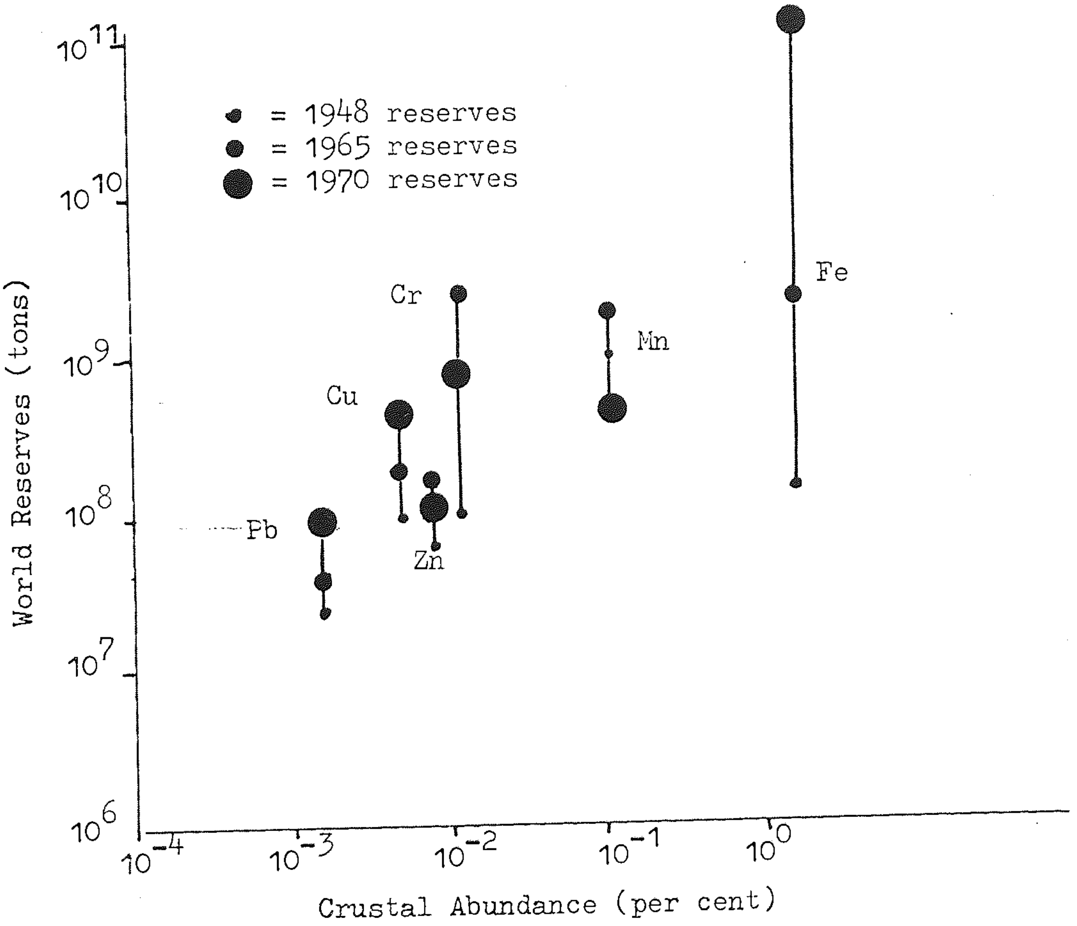


Figure 2.4 Variation of world reserves and crustal abundance with time (11)

The enormous increase in iron reserves is often cited as cause for optimism regarding reserves of other elements, but it is not geologically reasonable to assume that the concentrating mechanism of sedimentary processes will be duplicated for other elements.

What the relationship between crustal abundance and reserve size does indicate is that exploration should reveal considerable additional supplies of those metals which fall into the lower range of the relationship:

$$R = 6.8A \times 10^5 \quad \text{to} \quad R = 100A \times 10^5$$

A corollary is that if the upper limit of the relation is raised by new discoveries of one or more metals, it should give impetus for renewed exploration for other metals. Many of the materials that lie close to the upper limit line of Figure 2.3, are those sought and used in ancient times while those close to the lower limit are those relatively new to industry. This would suggest that new, large discoveries to raise the upper limit are unlikely.

This section has shown how reserves and resources are defined and their relative size illustrated. Prospects for an increase in reserve size have been examined and it is concluded that significant increases are unlikely for materials which have been used since historic times but that increases for the newer materials, such as aluminium, are likely.

2.2.4 The Time to Exhaustion of Various Materials

The time to exhaustion is a popular concept implying that at a certain future point in time no reserves of a material will be available for extraction. This takes no account of the Law of Conservation of Matter which strictly states that no matter can be created or destroyed. This means that although reserves (and resources) of a material may have been exhausted, material produced in the past still exists. In the case of hydrocarbon energy resources past production will exist in the form of carbon dioxide and water making recovery virtually impossible. In the case of most non-energy resources past production will exist in a relatively pure form although possibly widely dispersed. Such material has potential for recovery and if for example the concentration of copper ores falls to the equivalent concentration of copper in scrap automobiles or derelict buildings, then attention will be turned to these sources to help to satisfy continuing demand. In spite of these limitations, the time to exhaustion is a useful indicator of the availability of materials provided that its limitations are accepted.

In this section the various methods of determining the time to exhaustion will be examined and figures given for specific materials.

2.2.4.1 Renewable Resources

Renewable resources, as defined in Section 2.2.1, are not fixed in size, during any time period trees, for example, are at various stages of development from initial growth to decline. This dynamic behaviour contrasts with the static or fixed size of non-renewable resources and makes any realistic estimation of the time to exhaustion of renewable resources difficult, if not impossible. The problem is best explained by considering a given population of trees which, provided they are not too numerous and not over-exploited may be sustained indefinitely i.e. there is a Maximum Sustainable Yield which may be defined as the maximum production flow which may be sustained indefinitely without damage to the growth patterns involved, i.e. there is a virtually infinite time to exhaustion under these conditions.

If the Maximum Sustainable Yield is exceeded, for example by excessive tree felling, then the effects will be felt in future years when land errosion may occur. Lecomber (12) points out that in certain cases it may be optimal to exceed the Maximum Sustainable Yield but only if the temporary gain in production can be set against a fall in production of indefinite duration in future years. Such situations arise only when the time horizon is short, for example if there is a peak in demand for paper pulp after which a drop in demand is anticipated or when the value of future production is heavily discounted.

These factors make the time to exhaustion of renewable resources difficult to measure accurately for specific materials, with assessment varying from infinity to a few years depending upon the assumptions used. The case of an infinite time to exhaustion has already been discussed and is a result of careful resource management. The second case of a few years would arise, for example, if all land was deforested and used for building. For these reasons no further discussion will be devoted to the time to exhaustion of non-renewable resources.

2.2.4.2 Non-Renewable Resources; Static and Exponential Life Indices

The Static Life Index (SLI) is a measure of the number of years for which reserves could support global consumption at its present level. For example, for copper with a reserve size of 279 million tonnes and a world primary production of 5.34 million tonnes per annum (13), then

$$\text{SLI} = \frac{\text{reserve size (tonnes)}}{\text{current consumption (tonnes/annum)}} = \frac{279 \times 10^6}{5.34 \times 10^6} = .53 \text{ years}$$

The SLI is useful as a rough guide to the time to exhaustion of a material, but it does not reflect any changes in consumption levels. Its limitations are governed by the basic assumptions underlying its formulation, i.e. that reserve size and consumption will remain constant.

From the definition of a reserve given in Section 2.2.1 it is known that reserve size is not constant, but is a function of several other factors including:

1) Price of the material,
2) Grade of material,
3) Changes in extraction technology.

Of the above, the price of material is the most critical, affecting the reserve size by moving the reserve size boundary along the economic feasibility axis of Figure 2.1. As these movements in reserve size are unpredictable they cannot be used to modify the SLI to a more useful form except by updating reserve size as new reserve data becomes available.

Even a cursory examination of virtually any material will show an exponentially rising consumption curve with time. Figure 2.5 shows growth curves for copper, nickel, aluminium and human population. The Exponential Life Index (ELI) adapts the SLI to a more useful form by taking into acount exponential growth in consumption, but using the same reserve figure. The ELI is derived (by calculus) as:-

$$\text{ELI} = \frac{\text{Ln}[(r \times \text{SLI})+1]}{r} \quad \text{or} \quad \frac{\text{Ln}[(0.046 \times 53)+1]}{0.046} \quad \text{for copper}$$

$$= 27 \text{ years}$$

where ELI = Exponential Life Index (years)

SLI = Static Life Index (years)

r = annual fractional growth rate (i.e 6% per annum, r = 0.06)

Figure 2.6 shows the inaccuracy of the SLI for copper given that demand is increasing exponentially. Another more extreme example is that of chromium with a SLI of 420 years, which at a growth rate of 2.6 per cent per annum (1) reduces to an ELI of 95 years. The estimate of 2.6 per cent per annum growth rate is not critical as long as demand is increasing by as little as one per cent per annum, the SLI for copper reduced from 53 years to an ELI of 43 years.

Figure 2.6 also points out another implication of exponentially growing usage rates. New discoveries increase the ELI by only a relatively small amount. For example, at three per cent rate of growth in copper consumption, a SLI of 53 years corresponds to an ELI of 32 years. If the SLI were increased to 400 years, corresponding to an eightfold increase in reserves, the ELI increases only to 86 years, a factor increase of less than 2.7. Given exponentially rising demand, new discoveries of even the largest magnitude may only slightly increase the long-term availability.

Table 2.5 shows SLI and ELI estimates from three workers for various materials. The first column shows estimates for both SLI and ELI by Meadows (1) while the second and third columns show ELI estimates by Tien (16) and SLI estimates by Behren (17)

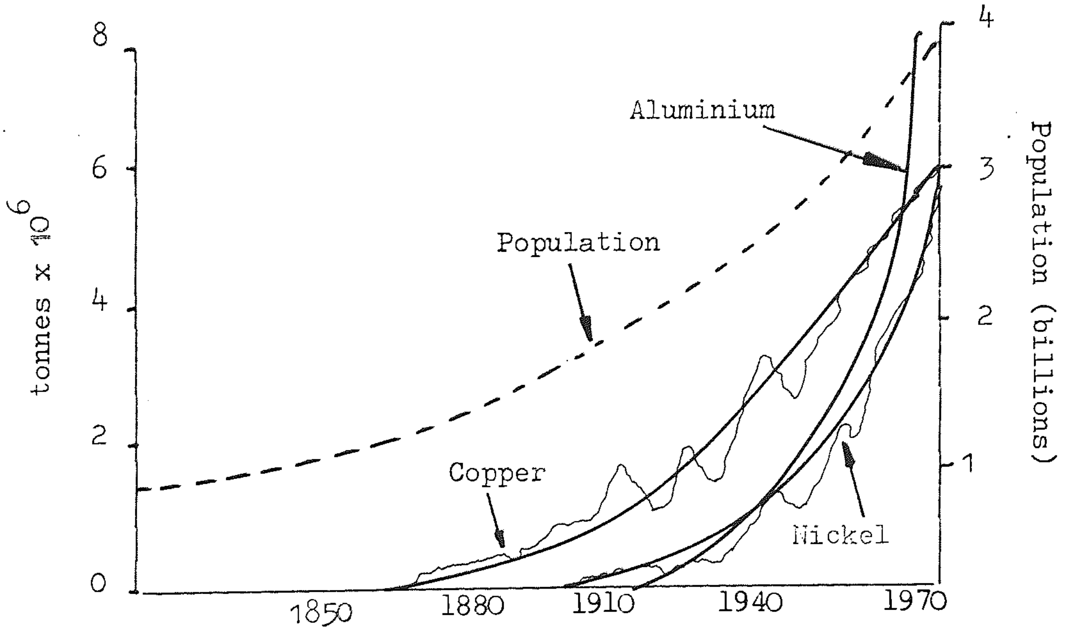


Figure 2.5 - Growth curves for copper, nickel, aluminium and human population since 1850 (14,15)

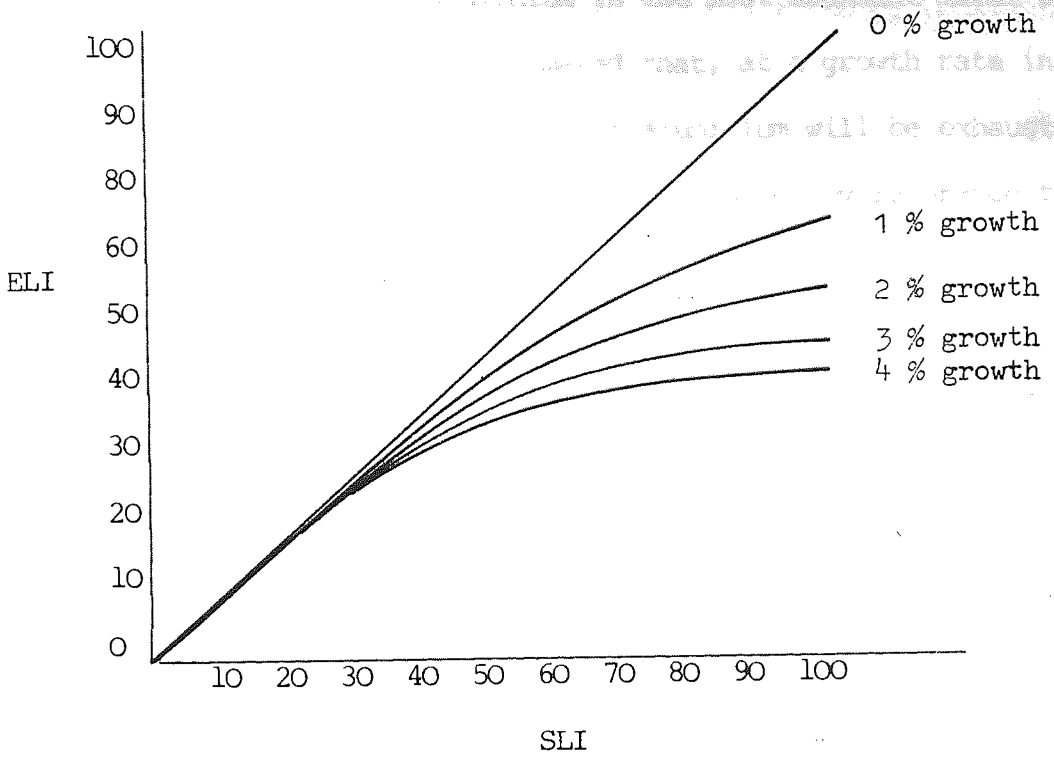


Figure 2.6 - ELI vs SLI as a function of annual growth rate for coppper

Table 2.5 - Static and Exponential Life Indexes for Various Materials

MATERIAL	Meadows (1)(1970)			Tiens (16)(1970)	Behren (17)(1970)
	SLI	ELI(a)	G(%)(b,c)	ELI(d)	SLI
Aluminium	100	31	6.4	35	175
Chromium	420	95	2.6	112	560
Cobalt	110	60	1.5		155
Copper	36	21	4.6	24	40
Gold	11	9	4.1		17
Iron	240	93	1.8	109	400
Lead	26	21	2.0		15
Manganese	97	46	2.9		180
Mercury	13	13	2.6		13
Molybdenum	79	34	4.5	36	100
Nickel	150	53	3.4		140
Pt Group	130	47	3.8		20
Silver	16	13	2.7	14	20
Tin	17	15	1.1		25
Tungsten	40	28	2.5	51	
Zinc	23	18	2.9	18	18

Notes
(a) calculated using G, i.e. average annual growth rates
(b) G = Average annual growth rate assumed.
(c) Source USBM Mineral Facts and Problems (1970)(13)
(d) Using assumed lowest predicted growth rate.

Except for silicon, aluminium is the most abundant metal in the earths crust and yet Meadows estimated that, at a growth rate in consumption of 6.4 per cent per annum, reserves of aluminium will be exhausted within 31 years. The apparent contradiction is resolved by reference to Meadows footnotes where he explains that he has counted only aluminium in known reserves of bauxite. Examining these footnotes in more detail, Meadows used as his source USBM Mineral Facts and Problems (1970)(13) which gives a 1965 estimate of bauxite reserves that was less than one half of the one given in the 1973 US Geological Survey document, US Mineral Resources (18) which was Meadows source for the remainder of his estimates. The 1973 document also points out that virtually inexhaustible potential reserves of aluminous materials other than bauxite exist.

As for iron, Meadows says that there may be reserves for only 93 years and that no estimates are available for potential reserves. This is only partly true. The 1973 US Mineral Resources (18) did not estimate hypothetical iron-ore resources beyond stating that they are enormous. Similar arguments relating to the definition of reserves may be put forward for magnesium and titanium with copper, zinc, manganese, chromium, lead, nickel and tin probably inexhaustible. Table 2.6 shows 1968 estimates of world consumption of certain metals together with an assessment of future supplies (19). Over 95 per cent of world demand by weight is for five metals which have long times to exhaustion even with high growth rates, ie. iron, aluminium, silicon, magnesium and titanium. Of the remaining five per cent, new discoveries, new sources, advancing technology, potential for recycling, substitution and functional design are all expected to make seven metals or 4.85 per cent of world demand probably inexhaustible. If the generally qualitative arguments put forward by Goeller and Weinberg (19) and Kahn (20) are correct then concern need only be felt for the remaining 0.04 percent of world demand, although it is difficult to believe that the effects of continuing exponential growth, particularly in Third World or less developed countries is not likely to have a significant impact upon the conclusions drawn.

In conclusion, the measurement of the time to exhaustion of important materials is a complex problem dependent upon the assumptions used in their formulation. Generally, future supplies of industrially important non-renewable resources cannot be guaranteed if historical exponential growth patterns continue. If these patterns do not continue, or if they continue at a much lower growth rate, then supplies will probably be met through new discoveries, advancing technology, substitution and changes in functional design. These factors are discussed in Sections 2.4, 2.5, and 2.6.

Table 2.6 - Consumption of Major Industrial Metals Considered Inexhaustible (19)

Metal	Percentage of World Consumption (1968)
Clearly Inexhaustible	
Iron	89.83
Aluminium	4.47
Silicon	0.71
Magnesium	0.09
Titanium	0.01
Sub-Total	95.11
Probably Inexhaustible	
Copper	1.35
Zinc	0.97
Manganese	1.76
Chromium	0.45
Lead	
Nickel	0.09
Tin	0.03
Sub-Total	4.85
TOTAL	99.96

2.3 MATERIAL FLOWS

Recycling may provide another means of reducing demand for virgin materials by utilising raw materials more effectively. In order to provide consistent terminology the opportunity is taken here to define terms to be used during the rest of this work, with particular reference to recycling and associated terminology.

2.3.1 Industrial Flows

Figure 2.7 shows the flow of a material through the sequence from extraction to discard.

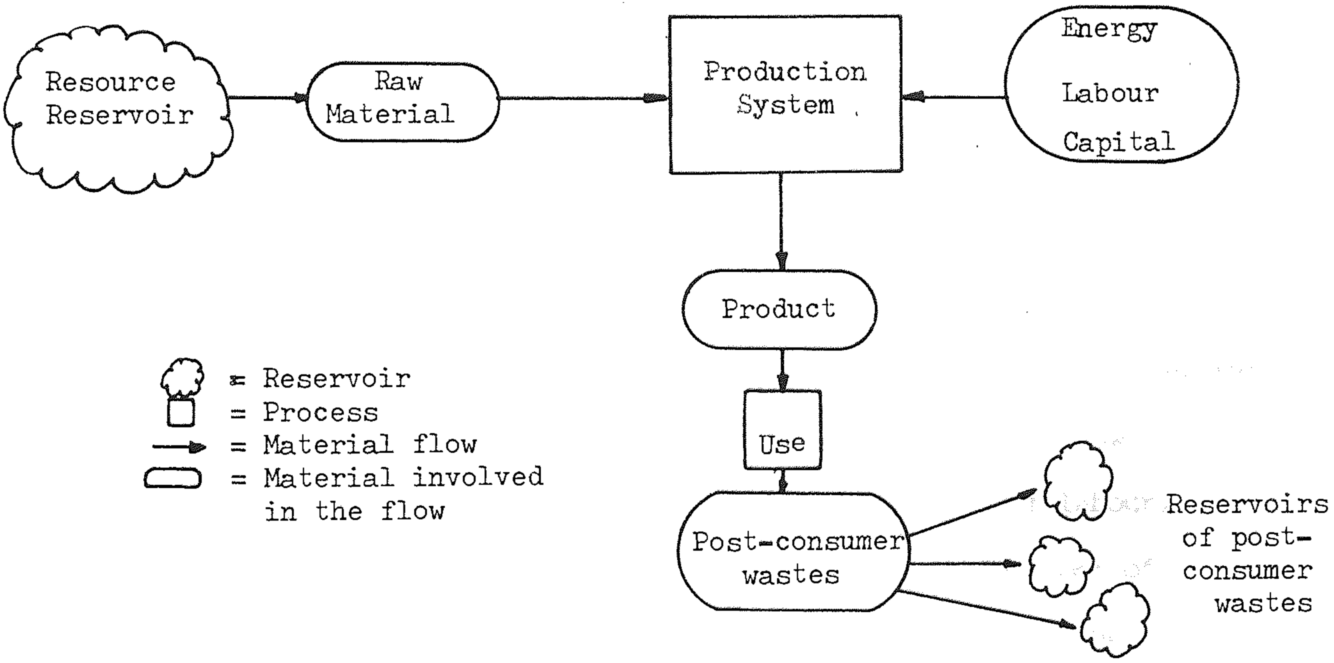


Figure 2.7 - Generalised Flow of a Material from Extraction to Being Discarded.

Raw materials, defined as materials in a form suitable for use as an input for the manufacture of product from that material, are extracted from the resource reservoir. The resource reservoir is a quantity of material, containing the raw material in question. If the resource reservoir is naturally occurring then the raw material extracted is called the primary or virgin raw material. The production systems uses labour, capital and energy to give an output in the form of a material or service.

The product then goes through a period of use during which its performance deteriorates until it is of no further use and is discarded, in this case to the environment where it contributes to a reservoir of similar discarded products. The size and location of these reservoirs vary from the concentrated domestic refuse stream, measured in millions of tonnes to the highly dispersed small reservoirs caused by the dropping of litter in rarely visited locations. One definition of wastes is materials that are cheaper to discard rather than collect and process, that is, of nearly zero economic value (at present). Wastes may be described as post-consumer waste, consumer waste, obsolete waste or residual. No production systems is one hundred per cent efficient and outputs other than the desired products arise. These production system wastes or non-product outputs are assumed, in this simplified example, to be discarded to the environment in a similar way to post-consumer wastes.

In Figure 2.7 extraction of material from the resource reservoir is generally preferred to reclamation of post-consumer waste. As the resource reservoir is used up there will be a shift towards lower grade raw materials with higher production process costs in the form of labour, capital and energy. Eventually a point is reached where the cost of collecting and processing post consumer discards in certain of the reservoirs of discarded products is less than that for the primary or virgin raw material and so they are used as a raw material instead, and so "recycling" takes place. A more exact definition of recycling will be given later and the term is used generally here.

2.3.2 Dissipative and Non-Dissipative Uses

Not all post-consumer wastes can be "recycled". Certain uses, for example zinc in paint and copper in fungicides disperse the metals so completely that there is no current or likely future possibility of their use as a raw material. These are termed dissipative uses. Other uses, for example paper in domestic refuse and copper tube in house demolition leave the post-consumer discards in a concentrated form in locations where recycling could take place. (The term post-consumer waste is not used as the materials in question do have an economic value. Instead, the term post-consumer discards has been used). These uses are defined as non-dissipative uses. Both dissipative and non-dissipative uses are shown schematically in Figure 2.8.

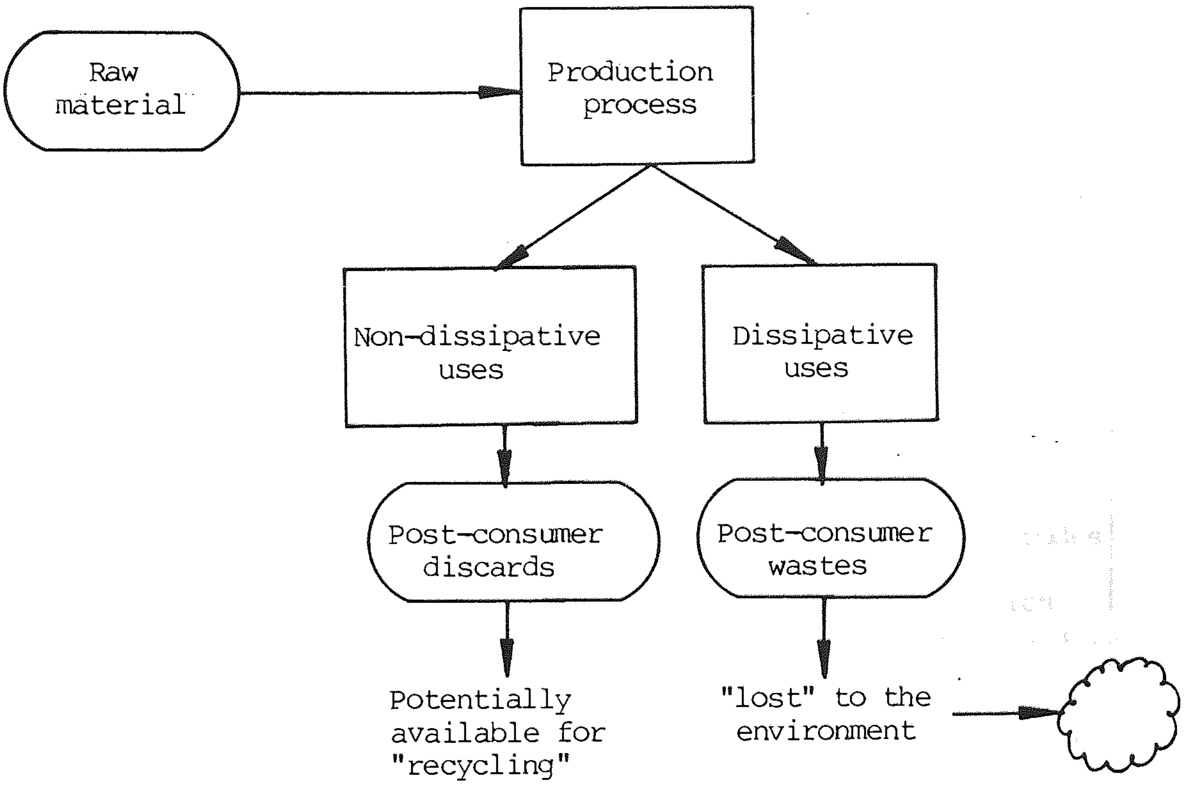


Figure 2.8 - Dissipative and non-dissipative uses

For economic, social and organisational reasons, rather than lack of technology much material is dissipated today that could be "recycled". A NATO report (21) estimated for Western countries the fraction of metals from mine production dissipated for various metals. These estimates are given in Table 2.7 and show that approximately 30 per cent of metals mined each year are consumed in dissipative uses with no possibility of

Table 2.7 - Dissipative Uses of Selected Metals in Western Countries (21)

Metal	Fraction of mine production dissipated beyond recovery	Examples	Fraction of mine production currently dissipated but technically (if uneconomically) recoverable	Examples	Total Fraction not recycled
Ag	0.2	Photographs Mirrors	0.3	Brazed joints Electrical contacts	0.5
Cd	0.5	Paint Printing Ink	0.5	Cd plating Plastics	1.0
Co	0.3	Pigments Paint driers	0.6	Magnets Cemented carbides	0.9
Cu	0.05	Fungicides lab. reagents	0.4	Car radiators Domestic appliances	0.45
Hg	0.5	Dental fillings Paints	0.3	Hg batteries Thermometers	0.8
Pb	0.3	Anti-knock compounds Ammunition	0.2	Bearing alloy Security seals	0.5
Pt	0.2	Razor blades	0.1	Electrical contacts Cardiac electrodes	0.3
Sb	0.4	Porcelain Flame retardants	0.1	Plastics Beaning alloys	0.5
Sn	0.2	Toothpastes Pesticides	0.6	Tinplate Collapsible tubes	0.8
W	0.3	Machine tool wear Ballpoint pens	0.6	Lamp filaments Welding rod stubs	0.9
Zn	0.4	Fencing wire Car tyres	0.55	Dry cells Die castings	0.95

recycling. Estimates for individual metals vary from 5 per cent for copper to 50 per cent for cadmium and mercury. Table 2.7 also shows the effect of economics upon the fraction of material available for recycling (i.e. from non-dissipative uses) of total mine production. Estimates vary from 10 per cent for platinum and antimony to 60 per cent for tin and tungsten, reflecting the end-uses of each material.

2.3.3 Waste Formation

There is a difference between production system waste (non-product outputs) and post consumer waste as defined in Section 2.3.1. Production system waste is normally of a known, consistent quality arising in known quantities and specific locations i.e. within the production systems. For these reasons, production system waste resembles the resource reservoir more closely than post consumer waste which is normally of variable quality and in unknown quantities and locations. As a result, production system wastes/discards are the first choice as a potential raw material source in place of, or supplementing, raw material from the resource reservoir.

Production systems may consist of three stages, concentration, forming and fabrication and production systems waste/discards may be broken down into two types according to the stage where they are generated, as shown later in Figure 2.9. The first type, home discards, or home scrap in the metals industry, arises from the first two stages of the production system, i.e. concentration and forming, when impurities are removed from the raw material and the necessary shapes for the third stage, fabrication are produced and consists of spillages, off-cuts and rejected material which can be fed directly back to the concentration or

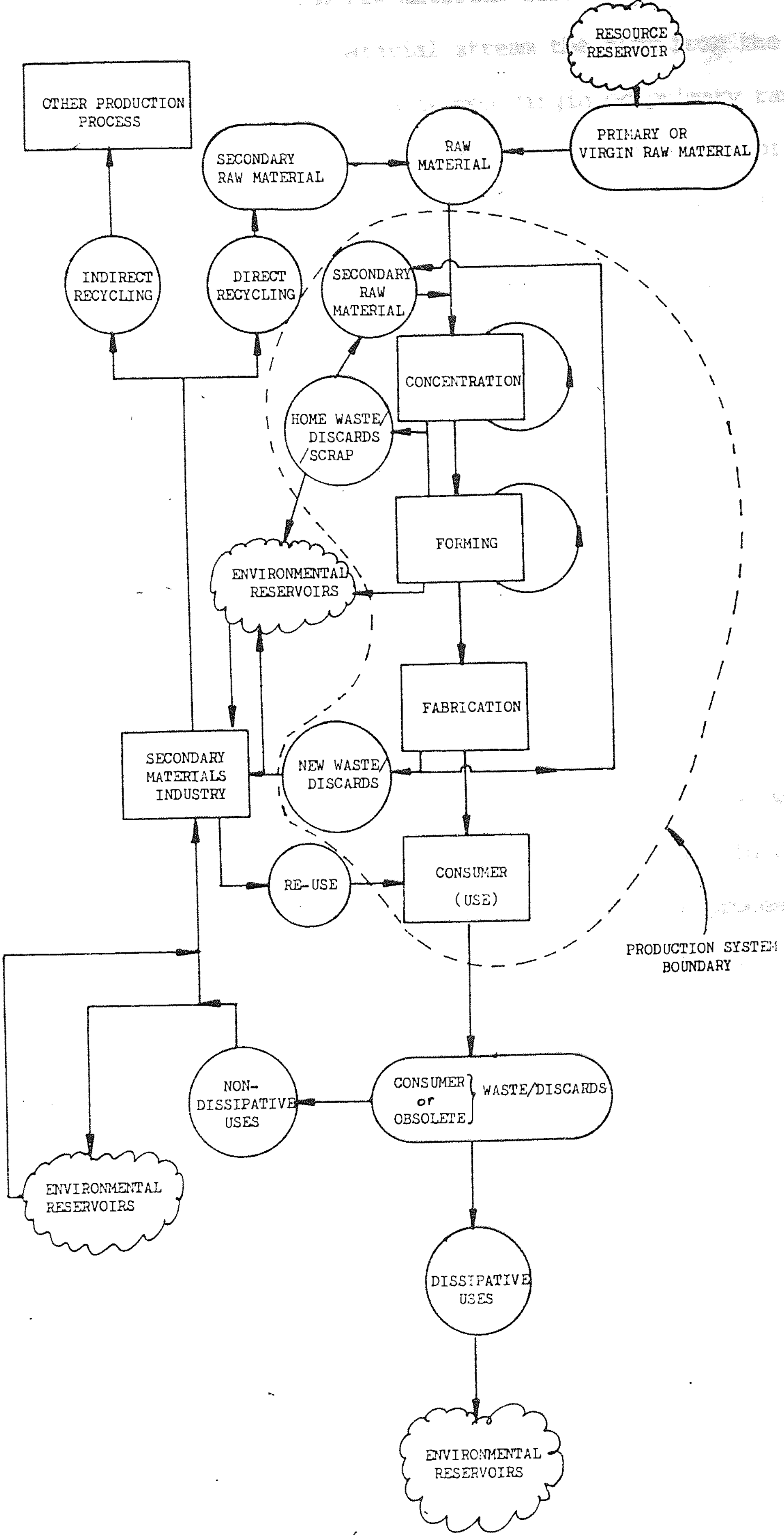


FIGURE 2.9 - INTERRELATIONSHIP OF THE DEFINITIONS GIVEN IN SECTION 2.3

forming stages and contribute to the raw material stream. To differentiate between these two inputs to the raw material stream the flow from the naturally occurring resource reservoir is termed virgin or primary raw material (a term used in Section 2.3.1), and the flow, in the form of home discards from the production system, secondary raw material. In modern industrial processes home discards are an essential component of the production process due to their known quality, quantity and convenient location and, where the concentrating and forming processes are associated in the same plant, this type of discard does not normally appear beyond the site walls i.e. it remains within the production process boundary shown in Figure 2.9.

The second type of production process waste/ discard/scrap is new waste or new discards/scrap which is a by-product of the fabrication stage of the production system. This material is normally associated with other materials so reducing its potential as a secondary raw material without further processing. The important role of new waste/scrap will be discussed in Chapter 4. New waste/scrap may be retained within the production system, but normally passes through the production process boundary where it either contributes to the secondary raw material stream or is discharged to an environmental reservoir, as shown in Figure 2.9.

2.3.4 Recycling

In the previous section recycling has been used as a general term covering the use of a material in some application after it has passed once through the production or consumer chain. This generalisation is useful but does not satisfactorily describe the various type of recycling which can take place. In this section these various types will be discussed generally. The various types of recycling are:-

1) Direct recycling (sometimes termed closed-loop recycling).

The use of a material for its original use after treatment e.g. bottles broken during use to cullet may then be treated to produce more glass bottles. Most direct recycling occurs in the production process (misshapen product etc.) as this is the most consistent source of high grade uncontaminated material. Some materials degrade in quality in recycling, paper and plastics being two examples and in this case the next type of recycling may be used.

2) Indirect recycling (or open-loop recycling)

The use of a material for a purpose different to its original use e.g. glass bottles for road surfaces. Indirect recycling is normally used for low grade discards as once a material is processed by indirect means it is usually no longer available for further reprocessing. A special type of indirect recycling is where the discard is converted under conditions which provide for harnessing the energy released often termed energy recycling.

3) Re-use

The reclamation of a material in its end form and its subsequent use in the same form e.g. the re-use of glass bottles as glass bottles.

Confusion often arises over the interchangeable use of the terms recycling, reclamation and re-use. In this report reclamation is defined as the separating out and recovery of material or energy from waste while recycling is a general term including reclamation and re-processing of waste materials while re-use, as defined earlier, is a specialised form of recycling.

Referring to Figure 2.9 there are three sources of potentially recyclable material. These are home waste, new waste and obsolete, non-dissipated waste. As discussed previously home waste is normally of consistent quality and supply in a location which enables its use as a raw material for the process of which it is a waste e.g. iron which has been retained in the sand troughs used to tap the blast furnace. When collected this iron may be fed directly back into the furnace. For these reasons home scrap is rarely seen outside the production system.

The other waste flows, new waste and obsolete waste may be assumed to pass to some form of independent waste processor. If a secondary material is defined as a material that has been through some end-use, such as obsolete waste then a secondary materials firm plant or operation is one which practices reclamation on this secondary material to produce a secondary raw material which is saleable. This material may then be used in direct or indirect recycling processes or re-used. Unfortunately in the U.S. the term secondary material firms, plant or operation is applied to both the firms processing the secondary material and to the firms using the secondary material. In the U.K. the term secondary materials firm is relatively rare, the terms scrap merchant, salvagers and reclaimers being more common. Figure 2.9 shows the primary and secondary chains together with the definitions given in this section.

This discussion of the large number and complexity of terms used in resource management and recycling has shown that a great deal of confusion can arise from their use unless care is taken to select the correct term. Additionally, recycling has been identified as a possible means of reducing the drain on virgin raw materials and lengthening the time to exhaustion of some potentially scarce materials identified in Section 2.2.4.

2.4 The Advantages and Disadvantages of Recycling

In Section 2.3 recycling was assumed to be a semi-automatic process dependent upon a few microeconomic criteria. In practice, the decision to recycle is a complex one involving micreconomics, macroeconomics and social costs together with political considerations. It is often stated that action should be taken to increase recycling activity but the advantages and disadvantages of such an increase and, in particular, the effect upon the U.K. has to be considered in the context of the above economic and social costs.

In this section, some of the major benefits and disadvantages will be examined and their effects noted so that decisions upon recycling activities can be discussed in later sections with a clear understanding of the potential effects of such decisions upon the parties involved. As such an examination is complex, some interreaction between sections will be necessary and in some cases only a brief discussion will be given because some aspects are beyond the scope of this project and are only included to describe the complexity of the problem. In order to provide a U.K. perspective and because many of the issues involved are national rather than global in nature, reference has been made to U.K. sources whenever possible.

2.4.1 Reduced Drain on Natural Resources

Section 2.3.2 demonstrated that not all waste products may be reclaimed and recycled due to dissipative uses. This give a theoretical upper limit to the fraction of material potentially recoverable as 0.95 for copper and 0.5 for mercury (as given in Table 2.7).

Taking the simplest case where consumption is assumed to be constant over the period under consideration then the Static Life Index (SLI) is given by

$$SLI = \frac{R}{C}$$

where R = reserve size (tonnes)
C = annual consumption (tonnes/year).

then if a fraction, f, is recycled, consumption of the resource equals C-fC and

$$SLI = \frac{R}{C - fC} \text{ or } \frac{R}{C(1-f)}$$

Since without recycling the SLI would hae been R/C then recycling has increased it by a factor of 1-f. Table 2.8 shows the effect of recycling upon a resource with a SLI of 100 years.

Table 2.8 - The Effect of Varying Recycling Rates Upon the SLI

Fraction recycled	SLI
0	100
0.25	133
0.50	200
0.75	400
0.80	500
0.90	1000
0.95	2000
0.99	10000

It can be seen that, in the case quoted in Table 2.8, the recycling of non-renewable resources will extend the SLI; but this will not be significant until a factor of 0.5 to 0.9 or above is reached. Table 2.7 has already shown that a factor of this order is not currently achieved meaning that a change in the dissipative uses of many materials is also necessary.

Section 2.2.4.2 showed that the ELI is a more accurate measure of the time to exhaustion of a resource than the SLI. Since the ELI involves a growth situation where more material is consumed every year then the fraction of material recycled each year (f) can never satisfy the total demand for that material. This is shown in Figure 2.10 below for a recycle fraction of 0.5 while Table 2.9 shows the effect of an increasing recycle fraction on the ELI of a material with a growth rate of 4% per annum in consumption, a commonly found growth rate for many materials (13).

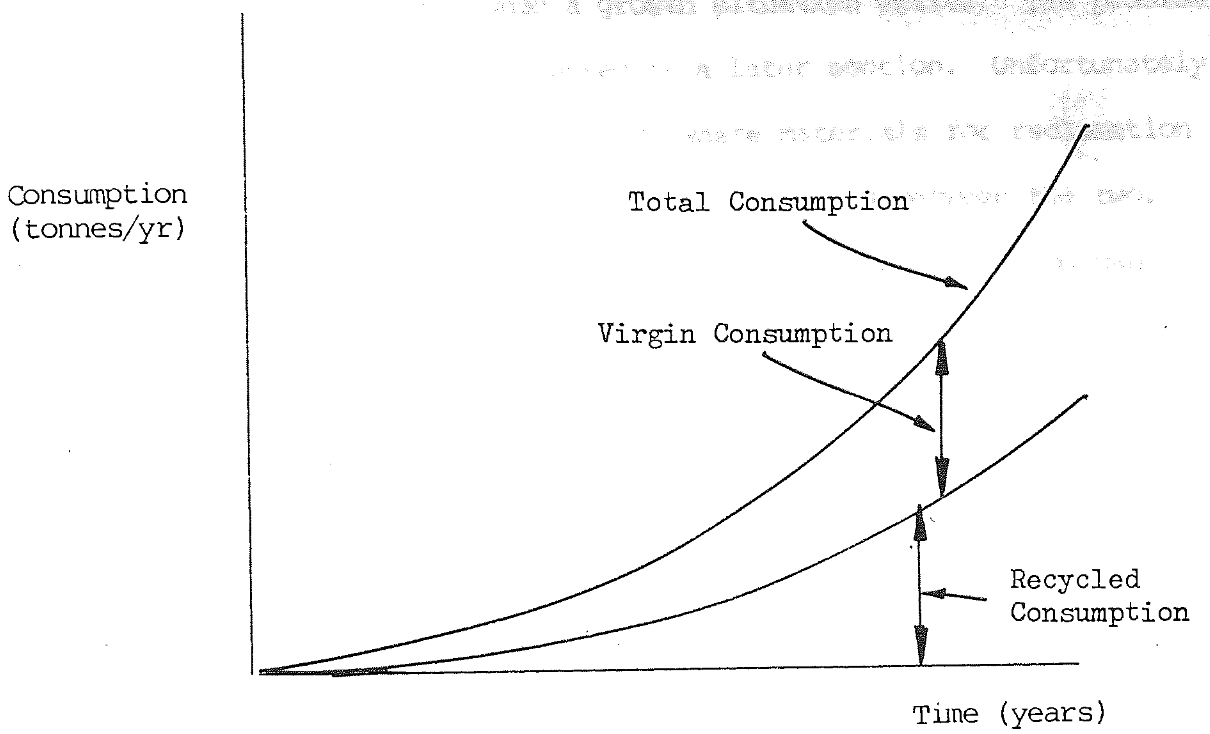


Figure 2.10 - Effect of a Recycle Fraction of 0.5 upon Total Consumption

Table 2.9 - ELI Estimates for Various Recycle Fractions

(growth rate - 4% per annum)

Recycle Fraction	ELI
0	40.2
0.25	46.2
0.50	54.9
0.75	70.8
0.80	76.1
0.90	92.8
0.95	109.9
0.99	149.8

It can be seen that even a recycle fraction of 0.99 will only result in an ELI of 150 years or 4 times the ELI at zero recycle fraction. Figure 2.10 and Table 2.9 show that recycling activities cannot result in a dramatic increase in the ELI when a growth situation exists. The problem of continuous growth will be discussed in a later section. Unfortunately, the real world does not normally provide waste materials for reclamation in the same year as consumption and a time-lag exists between the two. Figure 2.11 shows the effect of this time-lag i.e. that recycling can only provide a declining portion of the materials demand, assuming a constant recovery rate.

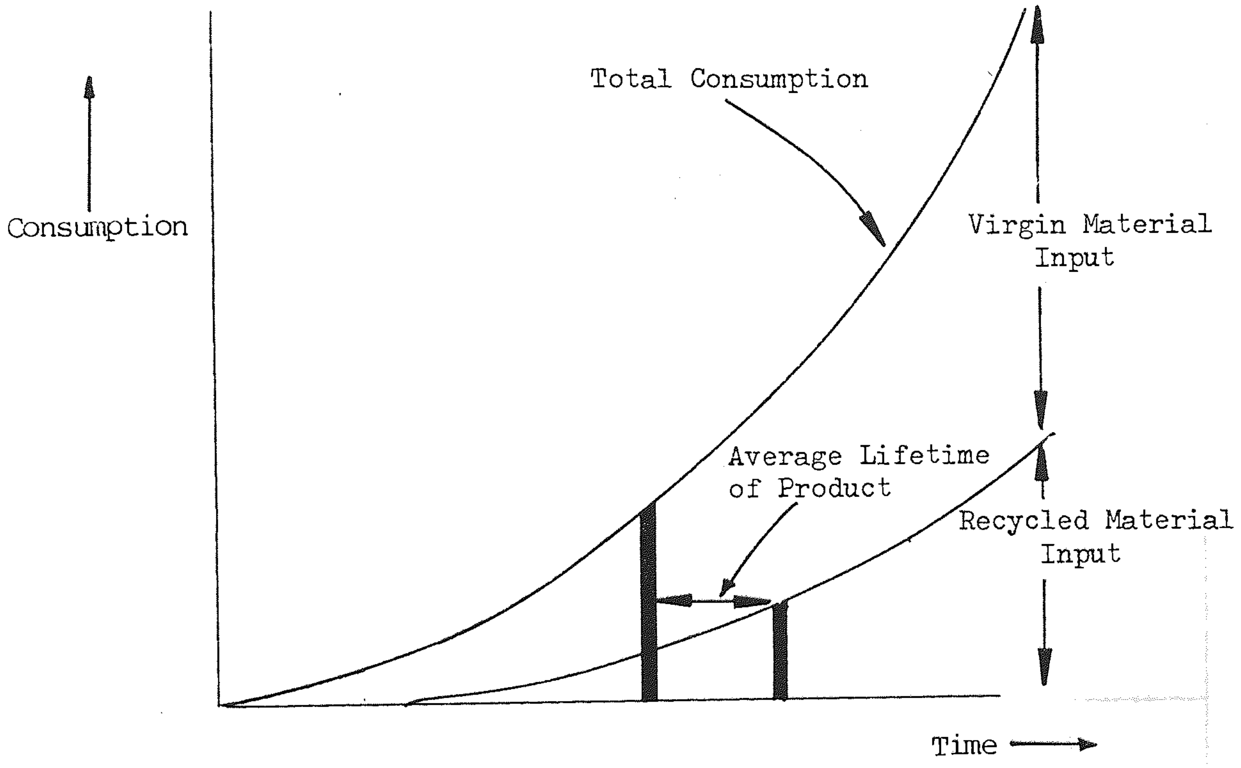


Figure 2.11 - Graph showing the relationship between Total Consumption and recycled input for a material of average lifetime L and recycle fraction 0-5.

Summarising, the argument that recycling will extend the time to exhaustion of resources is one of limited truth. If historic trends of exponential growth continue then recycling, can provide little effect on resource life.

2.4.2 Energy Savings

The saving in energy by the use of recycled material is often quoted as the major benefit of a recycle conscious society while the continuing rise in energy prices has caused an increased awareness of the problem.

In order to evaluate properly the energy benefits of recycling it is necessary to account for the energy used in the two competing processes ie. for material extracted from virgin and secondary sources. By analysing the competing processes it is possible to estimate any energy savings.

Various workers have attempted to assess energy savings from the use of recycled materials and typical results have been given in Table 2.10 for several metals.

Table 2.10 - Energy Saving from the Use of Various Recycled Metals

Material	Energy Saving (%) from use of sec material	Source
Aluminium	95	ORNL (22)
	95	Banks (23)
	95	Brooks (24)
	96	US NASMI (25)
Steel	40	NATO (21)
	74	USEPA (26)
	61	US NASMI (25)
	59	Kellogg (27)
Magnesium	98	ORNL (22)
	98	US NASMI (25)
Copper	77	US NASMI (25)
	74	Kellogg (27)
Titanium	58	US NASMI (25)
Nickel	90	Kellogg (27)
Zinc	72	Kellogg (27)
Lead	63	Kellogg (27)
Metals	20	Lincoln (28)

All the metals listed showed considerable energy savings with the highest being for magnesium (98%) and aluminium (95%) while lower savings (40-74%) were found for recycled steel compared to extraction from iron ore. The results quoted in Table 2.10 must be treated with care as in some cases it is not clear whether processing alone or processing plus collection energy costs have been included or whether processing inefficiencies have been included. Although most of the sources quoted qualify their estimates by stating that these process inefficiencies have not been included, Brooks (24) estimates that the energy saving due to the use of recycled aluminium would be reduced from 95 per cent to 60-70 per cent if they were included.

A more general survey, disappointing in its lack of quantitative detail, carried out for the Commision of the European Communities (29) found considerable potential energy savings for aluminium, lubricating oils and plastics and smaller energy savings for other non-ferrous and ferrous metals, paper, textiles and glass.

Care must be taken in applying these potential energy savings because of the technological limits to the amount of recycled material which can be included in a process. For example, current U.K. steelmaking practice uses up to 50 per cent scrap but the scrap used is subject to stringent quality control limitations to maintain impurity levels at acceptable levels. Although much concern has been expressed in recent years about levels of tramp metals such as copper and considerable research is in progress to enable utilisation of scrap containing these tramp impurities it is unlikely that increased energy savings will be realised from increased scrap usage for a number of years to come.

The increasing trend in the use of no-deposit bottles has serious energy saving implications. Berry and Makino (30) arrived at an energy saving of 66 per cent for returnable (i.e. re-used) glass bottles compared to non-returnable ones. While Boustead (31) quoted an energy saving figure of 99 per cent for similar applications excluding collection costs Hannon (32) arrived at a similar energy saving to Berry and Makino but went on to show that the energy costs, including collection, for recycling cullet is almost the same as that from virgin raw materials. Therefore the recycling of non-returnable bottles as cullet will offer little, if any, energy savings, and major savings may only be achieved by reuse i.e. returnable bottles.

In the future, manufacturing firms will feel a two pronged effect from energy prices. Not only will the real price of energy rise but the energy component of the production process will rise as lower grade materials are used. In the case of metals, the quality of ores is tending to diminish raising process energy costs. One of the most investigated metals in this respect is copper with Chapman (33) using his own brand of energy accounting (which includes the energy cost of the equipment necessary to the production process) estimating the relationship between copper ore grade and energy costs to be as shown in Figure 2.12 where it can be seen that energy costs rise sharply when the ore grade drops below 0.5 per cent copper. Current copper mines average 0.5 to 0.6 percent copper (34) although 0.25 per cent is not uncommon. This may increase the attractiveness of copper recycling in energy terms in future years.

It would appear that significant energy savings through the use of recycled and in particular reused materials exist. Closer examination of these savings show that large energy savings are achieved through current recycling practice and that energy savings from a marginal increase in recycling practice is unlikely to be significant. However, increasing

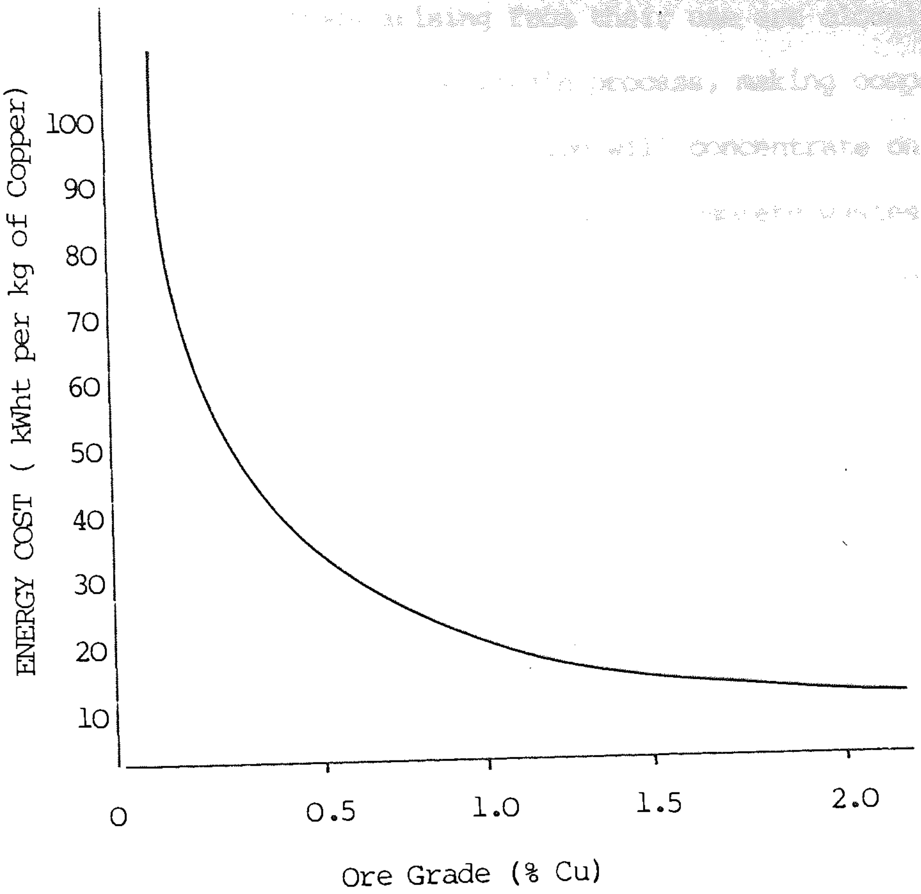


Figure 2.12 - Variation in Energy Cost of Copper with Ore Grade (33)

real energy costs and decreasing quality of virgin raw materials may influence future recycling decisions and stimulate research and development of processes to utilise more recycled material.

2.4.3 Investment Costs

The nature of some process system wastes and obsolete goods makes them a potential secondary raw material. In some cases the recovery process can be carried out with fewer and simpler operations than the virgin process with consequent investment cost savings.

As process system wastes do not generally leave the production system boundary and may be considered as a continually recycled internal stock, any investment cost savings arising from their use are closely linked with the investment costs for the virgin process, making comparison difficult. For this reason, this section will concentrate on the comparative investment costs for plants using obsolete wastes.

Data on investment costs for recycling plant are scarce with variations dependent upon the material concerned although one source (35) put forward a figure of 10-15% of primary production investment costs for secondary aluminium recovery. In view of this lack of data, a more simple approach based on the principle of Functional Units or Process Steps (36) may be adopted. This states that capital costs are directly proportional to the number of Functional Units or Process Steps involved.

Figure 2.13 shows a generalised flow diagram for the production of a material from virgin sources together with some possible flow processes utilising obsolete goods. By counting the number of steps for alternative processes it is possible to compare investment costs. The virgin process in Figure 2.13 involves five process steps while the most effective method of recycling, reuse, involves only three representing a cost saving of 40 per cent. Direct recycling on the other hand may involve four to six process steps or a 20 per cent increase or decrease in investment costs. Indirect recycling involves at least two process steps plus any additional process steps from the process system to which it is flowing.

While the numbers quoted above are fictitious due to a lack of empirical data they do show that investment costs are generally lower for recycled goods than for virgin goods, particularly in the case of re-use. However, care must be taken in interpreting the results of such an analysis as some, or all, of the virgin process steps may be located in another country raising investment costs for recycling activities in the U.K.

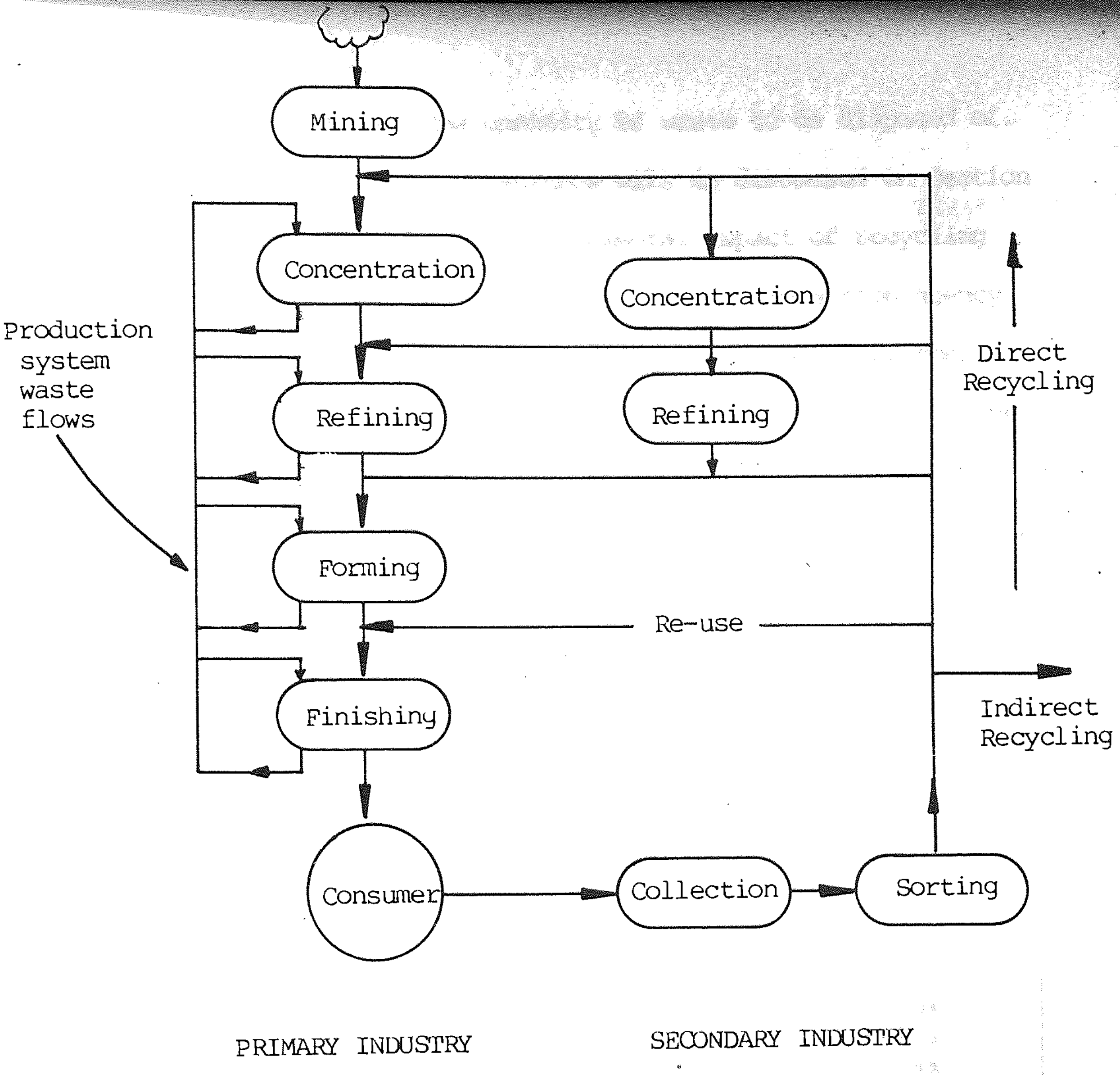


Figure 2.13 - Functional Unit Approach to Investment Costs

2.4.4 Environmental Impact

The production of both virgin and secondary materials can have an adverse effect on the environment. Extraction of virgin materials can give rise to considerable pollution. Pollution may also occur during processing and there is some evidence to suggest that overall there is less air and water pollution associated with the processing of secondary materials than with virgin materials. In addition, increased use of secondary materials will reduce the quantity of waste to be disposed of. The efect of this reduction in waste volumes will be discussed in Section 2.4.5. Little empirical work on the environmental impact of recycling has been found but a report by the U.S. Environmental Protection Agency (26) estimated the environmental effects of producing 1000 short tons (909 tonnes) of steel product from primary and secondary materials. The results are presented in Table 2.11 and show that air pollution is reduced by 86% and water pollution by 76% when 100% scrap is used in the steelmaking process.

Table 2.11 - Environmental Impact Comparison for the Production of 909 tonnes of Steel Produced from Primary and Secondary Materials (26)

Environmental Effect	100% primary material	100% waste	Change from recycling (a)
Primary materials (tonnes)	2071	1227	-90%
Water use (litres)	75.4×10^6	45×10^6	-40%
Energy cons. (kJ)	24.6×10^8	6.37×10^8	-74%
Air pollution (tonnes)	110	15.5	-86%
Water pollution (tonnes)	61.4	15.0	-76%
Consumer wastes generation (tonnes)	879	-54.4	-105%
Mining wastes (tonnes)	2591	57.3	-97%

Note (a) Negative numbers represent a decrease or an improvement by increased recycling.

Significant changes in environmental impact also occur if waste paper is substituted for wood pulp in the production of paper and board products. In particular the use of recycled paper requires less process water and in comparison with virgin material production causes less air and water pollution and generates less waste. There are certain disadvantages in the use of recycled pulp the main one being the production of water-borne solids associated with de-inking, bleaching and cooking processes necessary to upgrade the paper fibres. Table 2.12 shows that all environmental impacts are reduced if 100% waste paper is used to produce low-grade paper. The reduction is 73% in air pollution and 44% and 25% respectively for the biological oxygen demand and suspended solids. Table 2.13 shows the environmental impact resulting from the use of virgin pulp and de-inked waste paper to produce bleached kraft pulp and shows the well-known problem that de-inking tends to generate a water pollution problem in the form of suspended solids and an increase in process solid waste. Generally the environmental effects shown in Table 2.12 are reduced but it is not clear from Table 2.13 whether effluent treatment is included, although the figures quoted are probably the result of a comparative technical evaluation to determine the effluent produced. In practice, an effluent treatment plant would be associated with such a process which will increase investment and operational costs.

It is interesting to conjecture on how recycling activities will be affected by future developments. A continuing tightening in environmental legislation may be the single most important factor affecting virgin production and must have an effect on product price. In the USA it was estimated in 1977 that 4 or 5 cents/lb would need to be added to investment costs in the copper industry as a result of anti-pollution legislation (38)

Table 2.12 - Environmental Impact Comparison for 1000 tons of Low Grade Paper (37)

Environmental Effect	Unbleached Kraft Pulp (virgin)	Repulped Waste Paper (100%)	Change from increased recycling (%)(a)
Virgin materials use (tons)	1000	0	-100
Process water used (glsx10^6)	24	10	-61
Energy consumption (BTUx10^6)	17000	5000	-70
Air pollution (tons)	42	11	-73
Biological Oxygen Demand (tons)(b)	15	9	-44
Suspended solids (tons)(b)	8	6	-25
Process solid wastes (tons)	68	42	-39
Net post-consumer waste (tons)	850(c)	-250(d)	-129

Notes:

(a) Negative numbers represent a decrease in that category resulting from recycling.
(b) Based on surveys in 1968-1970.
(c) This assumes a 15% loss of fiber in the papermaking and converting processes.
(d) This assumes that 1,100 tons of waste paper would be needed to produce 1000 tons of pulp. Therefore, 850-1000 = -250 represents the net reduction of post-consumer waste.

Table 2.13 - Environmental Impacts from the Manufacture of 1000 tons of Bleached Virgin Kraft Pulp and Equivalent Manufactured from De-inked and Bleached Waste Paper (26)

Environmental Effect	Virgin Fiber Pulp	De-inked Pulp	Increased recycling change (%)(a)
Virgin materials use (tons)	1100	0	-100
Process water used (glsx10^6)	47	40	-15
Energy consumption (BTUx10^6)	23	9	-60
Air pollution (tons)	49	20	-60
Biological Oxygen Demand (tons)(b)	23	20	-13
Suspended solids (tons)(b)	24	77	+222
Process solid wastes (tons)	112	224	+100
Net post-consumer waste (tons)	850(c)	-550(d)	-165

Source and notes as Table 2.12.

when copper investment costs of 65-70 cents/lb were common. Trends towards tightening environmental legislation will increase the environmental costs involved. As there is very little primary production of a wide range of materials in the UK, current pollution levels arising from primary production processes in foreign countries have little local, but possibly major global effects. An increase in recycling activities in the UK would therefore tend to increase local pollution levels in the UK and this social cost must be balanced against other benefits. Energy recycling activities such as municipal incineration systems fluctuate in acceptability but the general real increase in the price of energy has made many such activities commercially attractive. If the energy conservation trend continues or increases then an increase in air pollution would result in the absence of further environmental constraints.

2.4.5 Volume of Waste for Disposal

The prompt industrial and obsolete wastes generated by the production system and utilisation of fabricated goods in a non-recycling society has to be disposed of to an environmental reservoir. By recycling some of the wastes involved the quantity or volume of these wastes may be reduced with a potential cost saving in disposal costs.

Wastes may simply be broken down into solid, liquid or gaseous forms. Liquid and gaseous wastes may arise during industrial processes but environmental and economic pressures restrict their loss while their generation during the industrial process is relatively small compared to solid waste. For these reasons, only solid wastes, as broken down in Table 2.14, will be considered here.

Table 2.14 - Type and Quantity of Solid Wastes Arising in the U.K. (39,40)

Type of Waste	Quantity (tonnes x 10^6)
Coal Mining Wastes	58
Other Mining Wastes	3
China clay quarrying wastes	22
Other quarrying wastes	27
Domestic refuse	18
Industrial waste	23
Ash and clinker from power stations	12

Table 2.14 shows that the major solid wastes are those involving earth moving operations with low unit value and so are normally laid down near to their source. Industrial waste disposal is constantly reviewed by the generating industry in an attempt to increase profitability. For this reason, the potential reduction in industrial waste volumes must be examined on an individual basis and is beyond the scope of this project although, for example, Whalley and Broadie (42) review the potential for industrial waste recovery in the non-ferrous metal industry.

The quantity of domestic refuse accepted by Waste Management Authorities in England for 1974/5 was 23.7 million tonnes (41) which reduces to 18.9 million tonnes for Great Britain after allowing for industrial wastes handled and including refuse generated in Scotland and Wales. Over the period 1934 to 1974 domestic refuse generation per person per week rose by approximately 20 per cent in weight terms (41,43) while population increased by 19 per cent from 47 to 56 millions. As a result the refuse handled increased in weight by 39 per cent from 13.6 million tonnes in 1934 to 18.9 million tonnes in 1974. Perhaps more important, in terms of the costs of the major domestic refuse disposal practice, controlled landfill (accounting for 81 per cent of all disposals in 1974/75 (41), the volume of waste has increased by a larger amount than in weight terms. Over the period 1935 to 1968 the volume increase was 44 per cent with a further 33 per cent increase expected by 1980 (44). Figure 2.14 shows that, in weight terms, low density materials and in particular paper and plastics have increased their share of total domestic refuse handled while the high density dust and cinders have decreased. It has been estimated (45) that more than £7 million worth of metals alone are lost annually (1974 prices) in domestic refuse representing a significant saving on the U.K. import bill if recycling took place, but disposal has been the method of dealing with refuse for many years and cannot be replaced overnight. Even with gradual change it is necessary to examine the alternatives before recommending their adoption or in other cases rejection. In particular, the economic and environmental aspects of various schemes need to be analysed to prevent, for example, the energy saving identified in Section 2.4.2 for secondary aluminium being exceeded by the energy required to separate aluminium waste from refuse. Technology on suitable processes to increase recycling and decrease the quantity of domestic refuse for disposal is abundant, but economic evaluation is lacking and it is in this area that work is most needed.

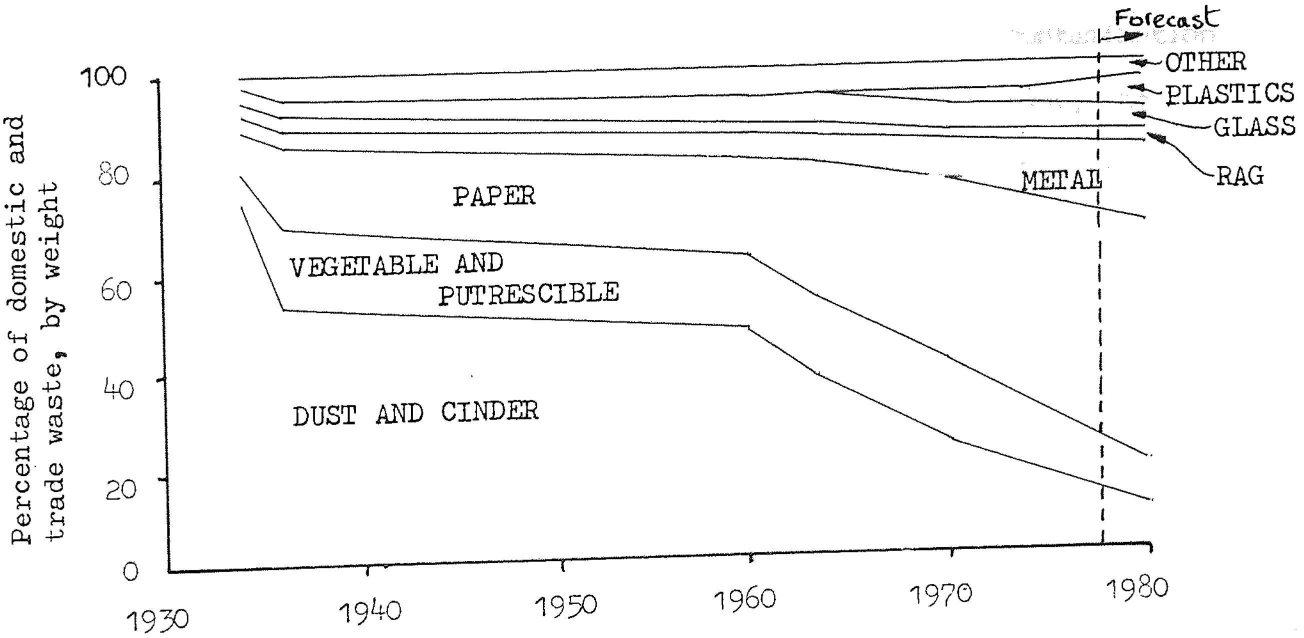


Figure 2.14 - Composition of Domestic and Trade Refuse 1934 to 1980 (43,44,46)

2.4.6 Consumer Attitudes

The consumer and his attitudes can contribute to recycling efforts in one of two ways. Firstly, the consumer is a generator of potentially recyclable materials and with suitable economic and social conditions will assist in the segregation of waste materials at source into forms conducive to reducing recycling costs. Some metals already enjoy a steady high level of segregation at source and delivery to a suitable merchant because of their inherent value. Examples include iron and steel, copper and lead while consumers would not deliberately dispose of gold and silver in domestic refuse.

Other materials, such as paper, are of a lower value and are collected and delivered to a suitable merchant on a much more sporadic basis dependent upon current demand. Various schemes have been considered and attempted to promote source separation of wastes, the most common material involved being glass. For example, in York, a pilot scheme was inaugurated covering a thousand households to allow separate collection of glass containers sorted by the householder into clear and coloured containers. In this scheme, initial success was followed by a drop in the strict contamination levels demanded by the users of the collected glass. In contrast, the various bottle banks set up across the country are working very well after a much longer period as are the various paper collecting schemes operated by volunteer organisations.

It would appear then, that volunteer schemes, whether for paper or glass are more effecive than "compulsory" schemes. The reasons for this are unclear but one explanation could be that the majority of people who use bottle banks or collect paper are those with an interest in the environment and the society in which they live and are willing to give up some of their time for no tangible benefit. In contrast, the schemes operated by local authorities envelope the community as a whole and involve a section whose lack of social conscience can adversely affect the efforts of others. Additionally, the stop-go attitudes of some local authorities towards recycling can influence the consumers own attitude even though the local authorities actions may be dictated by the economics involved and in particular demand for the waste product. Separate waste paper collection is a good example of this, with many local authorities stopping separate collection.

The second way in which consumer attitudes can contribute to recycling effort is by using recycled goods in preference to those produced from virgin materials. The commonly quoted reasons for using recycled goods are the benefit to national interests, in particular the balance of payments, reduced cost of product and lower disposal costs (and possibly a reduction in rates). Unfortunately, secondary raw materials and goods produced from such materials still have a reputation for inferior quality which is often deliberately exploited by virgin materials users. For example the Woolmark does not allow the use of post consumer textiles in goods carrying its mark (48) and many manufacturers of goods using recycled goods are unwilling to promote this aspect of their product because they feel that consumers will not buy on aesthetic grounds. This view is supported by Riordan and Turner (47) who found that the purchasing decision for paper depends upon the quality (texture and colour) of the paper which may mean marketing difficulties for firms anxious to produce recycled paper yet keen to compete in the paper market. Advertising can play a large role in changing consumer attitudes. The acceptance, for example, that recycled oils are inferior quality materials that should only be used when no alternatives exist may be replaced, by suitable advertising, by a more positive promotion of their use.

The above discussion shows that an intrinsic desire to recycle exists among a certain proportion of the community built upon a social conscience and/or some economic benefit but that ideals and actions may not coincide.

NO PAGE 50

2.4.7 Benefit to Balance of Payments

The contribution of recycling activities to the Balance of Payments may take one or both of two forms. Firstly, additional recycling may reduce the import bill for raw materials or finished products. Secondly, recovered materials, possibly in the form of finished products, could be exported and also reduce any Balance of Payment deficit.

Any savings in the import bill must take into account the cost of the virgin raw material, the cost of reclamation and processing of the secondary material and the market value of the reclaimed material. An EEC sponsored project (29) examined these costs and found that the following materials showed large savings in imports due to increased recycling effort : iron ore; non-ferrous metals (other than aluminium); wood pulp; plastics; rubber; textiles and lubricating oils. Materials showing small import savings are aluminium and glass. Unfortunately, no reasons for these savings were given. Balance of Payments savings are important, particularly in time of recession when investment capital is limited. Instead of spending a sum of money on importing raw materials which may only pass through the production process once, investment in a recycling activity enables the same money to be invested in the U.K. in the form of employment, stability of supply and capital plant which can be used to process materials many times. In Sweden, paper pulp is the major foreign currency earner and rather than use domestic virgin pulp to satisfy growing domestic demand central and local government and the paper industry are promoting the use of waste paper to maintain foreign earnings from virgin pulp exports. Existing recycling practices already contribute to a balance of payments saving. For example, Thomas (45) estimates that U.K. waste paper recycling saves about £500 millions in foreign currency each year.

2.4.8 Strategic Considerations

Industrialised societies rely upon a continuing supply of virgin materials to continue production. These virgin materials tend to flow from the less developed Third World countries to the industrialised or developed countries. The continuing delicate balance of world affairs means that international disputes could seriously affect the flow of virgin materials, even to countries not involved in the dispute. In such a situation, the stock or reservoir of unrecycled material could become a major supply source enabling production of strategic materials to continue. Generally speaking, while modern societies might appear to be vulnerable to a sudden severe shortage of energy or food, they have rarely been desperately vulnerable to shortages of raw materials. For example, even during wartime, when raw materials were in short supply and industry was redirected to the needs of a wartime economy, the major needs (i.e. those necessary to fight the war) were satisfied by mixing the existing raw material supplies with recycled material and substituting for those materials in short supply, e.g. pure iron for copper in World War I.

In a society where recycling was much more important to the industrial process than at present, periods of limited raw material supplies would have a more dramatic effect as no recyclable stock exists. For example, if all the copper potentially available for recycling was utilised at the time it arose prior to World War II, then during the war there would be no other source of copper other than imported virgin copper. In practice, such a situation is unlikely to arise, but must be considered if recycling activities are to be increased.

2.5 The Optimum Recycle Rate

2.5.1 Private and Social Costs of Recycling

In private industry, the decision to recycle is generally thought to be determined by the monetary difference between virgin and secondary material costs so that total costs, C, are minimised i.e.

$C = V + R$ where V = costs of virgin material

R = costs of secondary or recycled material.

This approach ignores the social costs and benefits associated with recycling as the primary aim of most companies is maximisation of profits. Thus, the company will normally buy its raw materials and dispose of its wastes as cheaply as possible. This may involve leaving open-cast mines unfilled and indiscriminate dumping of wastes so externalising the social costs involved to the society within which the company operates.

The social aim is to minimise the sum, S, of the private costs, C, and the external costs involved including pollution and any reduction in the static life index associated wih the use of virgin or recycled material, i.e. to minimise:

$$S = V + R + E_V + E_R - F - L$$

where E_V = total external costs associated with virgin material use

E_R = total external costs associated with recycled material use

F = benefit associated with extension of resource life

L = benefit associated with gains in land now available for other uses.

Figure 2.15 shows this analysis in diagrammatic terms. If a recycle ratio, r, is defined so that at 100 per cent virgin material use, $r = 0$ and at 100 per cent recycled material use, $r = 1$, as shown on the horizontal axis of Figure 2.15, then R will rise as r approaches one as recycled supplies are more expensive to collect and process. V on the other hand will be zero when r = 1 and positive if r is less than one. Similarly E_V will fall and Er rise as recycling increases.

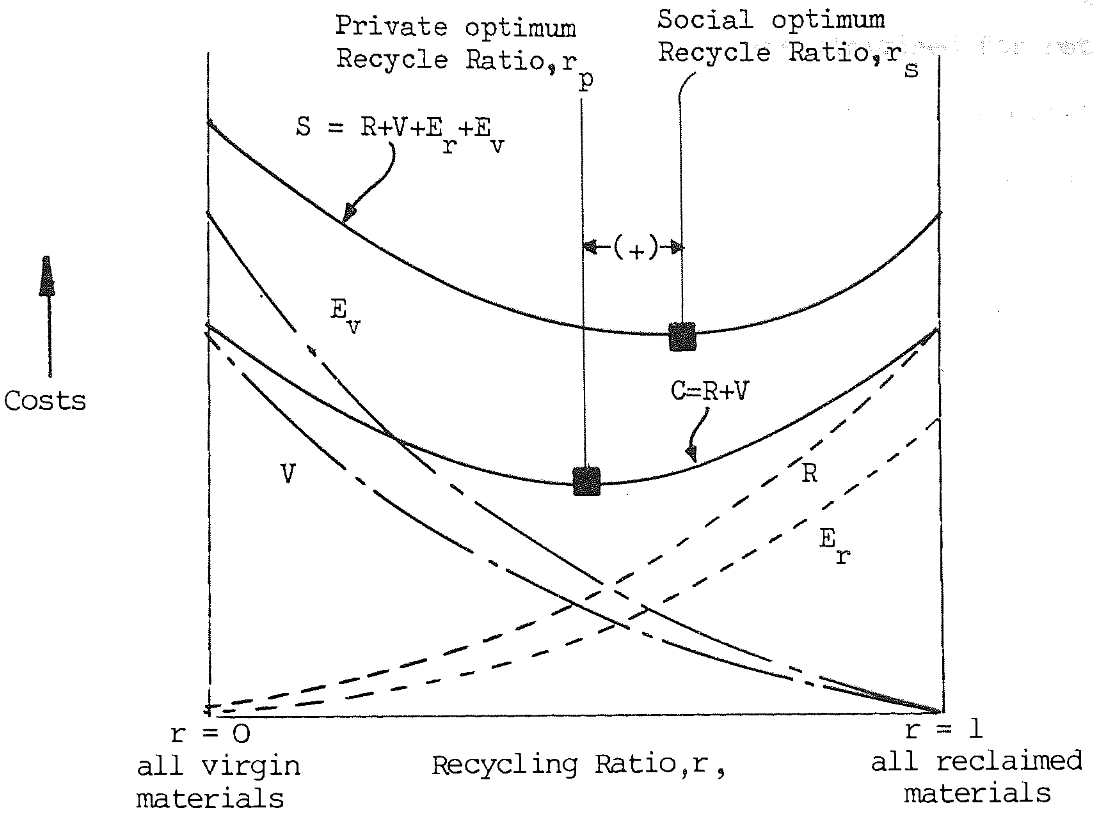


Figure 2.15 - Private and Social Optimal Recycling Ratio adopted from (3)

In Figure 2.15 rs (the social optimum recycle ratio) lies to the right of rp (the private optimum recycle ratio), implying that more recycling is socially desirable than private industry is willing to provide. It is also possible for r_s to lie to the left of rp, implying that recycling should be reduced rather than increased. This will arise if, for example, recycling technologies are more polluting than the disposal of virgin waste. No generalised conclusion is possible and only individual case studies will show the answer for each problem. Although Pearce (49) and Henstock (50) refer to the mechanisms of Figure 2.15 as developed by Spofford (51) little empirical work by these or other workers has been found in published material. Fisher (52) attempted to ascertain the external or social costs of returnable and non-returnable bottles. Although unable to use the limited U.K. data, an analysis of U.S. and European data showed that the returnable system generated less external costs than the non-returnable. It has been suggested (53) that the total costs are minimised for returnable bottles when the bottle has been reused five times. Another report (54) discussed the problems of estimating private and social costs for the same material while Conn (55) considered the empirical assessment of social values as being difficult if not impossible. The assessment of private and social costs involved in recycling is considered to be too complex a problem for further investigation in this project. Figure 2.15 shows that intervention, possibly in the form of fiscal incentives is necessary to raise (or lower) the recycle ratio to the social optimum from the private optimum.

2.5.2 Fiscal Incentives for Recycling

In the previous section a need was identified for means of equalising private and social costs to achieve the optimum recycle ratio. Suitable incentives should be designed to encourage further recycling by taking into account the reasons why discarded material is not at present recovered. The fundamental obstacle may be that it is not financially advantageous for industry to recycle material and fiscal incentives can increase both supply and demand for secondary materials. Fiscal incentives are, in essence, tax measures the aim of which is to make the economic climate for recycling more favourable and can include direct taxes, levies, grants and subsidies.

In this section the most common types of fiscal incentives abstracted from various sources will be briefly discussed with a more detailed examination with reference to specific materials made in later chapters.

1) Disposal Tax

A disposal tax is a tax levied on a product appropriate to correct the divergence between private and social costs and so should reflect the average costs associated with the collection and disposal of discarded product with suitable allowances, in the form of deductions or avoidance of tax, included for recyclable materials. The key factor in a disposal tax is the accuracy of measurement of the private costs and particularly the social costs of disposal. An example of a disposal tax is a tax on total or excess packaging which takes into account the nature of the excess and whether it can be recycled or not so that the producer pays for its disposal and not the community. If the disposal tax was charged on a value basis then the costs of packaging would be reduced and cheaper, possibly recycled, packaging would be used. If the disposal tax was charged on weight basis, then the quantity of waste generated would drop, decreasing the quantity of waste for disposal (see Section 2.4.5).

2) Virgin Materials Tax

A virgin materials tax is a tax applied to limit the use of virgin materials by artificially raising the price to a level reflecting the full social cost of their use in preference to recycled materials so stimulating recycling and encouraging more profitable use of virgin materials. Examples include an import levy on low grade paper pulp to encourage the use of recycled paper, also assessing the energy requirement of virgin and recycled materials and taxing the higher energy process.

3) Virgin Materials Levy

Levies imposed by producer countries on virgin materials to restrict consumption. It is in fact a negative incentive applied usually by producing countries to prevent rapid rundown of valuable finite virgin material reserves. Theoretically, such a levy would rise in inverse proportion to the estimated lifetime of the reserves coupled with control over the rate of extraction, so that an increasing price differential, coupled with strictly controlled availability, will encourage recycling. The United Kingdom would be likely to be at the receiving end of such a levy such as currently exists on OPEC oil prices.

4) General Pollution Tax

A General Pollution Tax, often referred to as a "Polluter-pays" tax is a non-discriminatory tax where the process which gives rise to less pollution would be favoured whether virgin or secondary materials were involved. The environmental impact per unit output would be compared with substitute processes and materials, including recycling, and the use of taxes would provide an incentive for the utilisation of the product with the lower environmental impact. Questions which must be answered with a General Pollution Tax revolve around the argument that a Pollution Tax would create a license to pollute with the tax being passed on to the consumer so that producers would not reduce their pollution levels. An alternative to a direct general pollution tax is to impose legislation restricting pollution levels. Such legislation, similar to the 1974 Control of Pollution Act, makes it illegal to dispose of a pollutant and/or waste in an indiscriminate fashion and applies both to primary and secondary material producers making it easier for the process with less pollution to operate without considerable expense in pollution control equipment.

5) Direct Subsidies for Recycler/Reclaimers

Direct subsidies for recyclers/reclaimers through grants, price support systems and accelerated depreciation allowances on equipment, plant and buildings used wholly for reclamation and recycling would encourage the use of recycled materials. The maximum subsidy for recyclers in principle would equal the full social costs of post consumer waste disposal. Difficulties in segregating the already high proportion of prompt industrial scrap used and post-consumer wastes would make implementation and enforcement difficult without developing the necessary data collection system.

6) Direct Incentives to Reclaimed Material Users

Direct incentives to users of reclaimed materials could be applied in two ways. In the first, tax allowances would inflate sales proceeds so reducing taxable profits or a straight forward subsidy or tax allowance for the users of recycled, as opposed to virgin materials, could be operated. The second method is to provide a price support mechanism so that excess stocks of recycled materials are used at times of low demand so that these stocks do not drive the price even lower. In essence, this is a similar scheme to the EEC Common Agricultural Policy.

The incentives discussed above are general and a great deal of interaction can occur. Specific regulations can have an attraction by insisting upon design or durability features leading to more efficient resource utilisation (see Section 2.6.2). Such regulations have to be specific, aimed at a particular product or range of products for enforcement to be possible and a comprehensive policy is necessary to ensure fairness to all interested parties. The final question to be asked of any fiscal scheme is "How much will it cost to operate this scheme?" The area of fiscal incentives and their effects on recycling and pollution has been widely discussed. For example, see (49) and (56 to 62).

2.5.3 Technological Means of Increasing the Recycle Ratio

In the previous section fiscal incentives to increase the recycle ratio were presented. In this section the technological means of achieving the socially optimum recycle ratio will be discussed. These engineering methods should concentrate on the following factors which would tend to raise the rate of utilisation of secondary materials:

1) Design of new products to facilitate recycling after use.

2) Design of products utilising an increased proportion of recycled materials.

3) Improving systems for the extraction and recycling of discarded material.

The design of new products to facilitate recycling after use is principally governed by the economics of extraction, such as dismantling consumer goods to yield usable grades of material. These economics are a major cost in recycling and can be unsatisfactory due to certain features of the discarded good. Herstock (63) identified three main areas adversely affecting the possibility of designing new products to facilitate recycling as being:-

1) Complex construction involving a multiplicity of materials, often inextricably united with one another e.g. in electroplated articles.

2) Miniaturisation of components e.g. in electronic equipment.

3) Progressive replacement of materials that possess a scrap value by other with no well-defined secondary market e.g. replacement of metals by polymers.

Design of new products to facilitate recycling is contrary to these trends and a radical rethink in design philosophy, possibly instigated by the fiscal incentives described in the previous section, would be necessary before the trends could be reversed. An example of design for recycling is the suggestion (64) that all the copper containing parts of a car should be located in one or two standard places on a car for ease of removal. Scrap steel from cars is often unacceptable to the steelmakers because of copper contamination and this measure would benefit both the copper and steel industries. An alternative is to replace all copper in cars by aluminium which is not retained in the steelmaking process, a step which would benefit the steel, but not the copper industry.

The design of products utilising an increased proportion of recycled materials again is not a straightforward engineering problem as consumer attitudes (already discussed in Section 2.4.5) and economics are vital factors. The engineering aspect is limited by the fact that any material that has entered service is likely to have become contaminated with materials unsuitable for recycling by conventional technology. Secondary materials subsequently produced from these discarded goods would become a recirculating load acquiring further contamination during each successive re-manufacture. This limits the use of secondary materials so that a blend of virgin and secondary materials would give an acceptable contaminant level. This point varies with the individual material and product manufactured although copper in car steel scrap is a good example. Henstock (63) gives tinplate as an example where innovations such as:-

1) Increasing use of lacquered containers, so reducing tinplate thickness;

2) Two piece drawn cans replacing three piece cans.

3) The introduction of tin-free steel where the tinplate is replaced by a thin layer of chromium which enters the slag during the steelmaking process rather than the steel as in the case of tinplate;

would decrease contamination levels and increase recycling activity. The economic aspect is governed by the engineers desire to achieve a compromise optimising satisfactory properties at minimum overall cost. Such a compromise may not favour the use of recycled material and once again the fiscal incentives described in the previous section may need to be implemented. The Netherlands government operates a scheme (48) which, through taxes, limits the production of goods which because of their nature, composition, weight or volume are difficult to recover.

2.6 The Alternatives to Recycling

In previous sections a need for concern over future supplies of non-renewable materials was identified and recycling identified as a possible method of reducing the drain on natural resources. There are other means apart from recycling which would appear to offer a reduced drain on these resources. Possible alternatives are discussed below, in a general manner, but as a detailed discussion is outside the scope of this project only a general outline will be given.

2.6.1 Increased Extraction Efficiency

In section 2.2.2 the definition of reserves was given as the portion of an identified resource from which a usable commodity can be economically and legally extracted at the time of determination. Implicit in this definition is the fact that not all of an identified economic resource is extracted, indeed in the case of oil the recovery rate averages only about 30% of oil originally in place over the world as a whole (65,66). Although oil recovery technology has been improving and secondary and tertiary recovery methods are being implemented, Table 2.15 shows that even with expensive tertiary extraction methods the recovery rate will only be raised to 65% (67) maximum. Although 100% recovery is practically impossible achieving 65% would increase current reserves by two times.

In mining, the method of extraction is generally the most important factor in assessing reserve size. Surface mining permits more flexibility in production including at least theoretically the ability to obtain 100% extraction. In underground mining the ground support system limits recovery but recent shifts from selective to mass mining techniques have increased extraction efficiencies.

Table 2.15 - Secondary and Tertiary Recovery Methods for Oil (68)

Recovery Methods	Normal range of recovery improvement (%)	
	from	to
Secondary		
Waterflood	10-20	30-50
Steam (heavy oil)	10	60
Tertiary (after watered out)		
Alternate gas-water	30	40
Thickened water (polymer)	30	40
Wettability reversal	45	55
Miscible-hydrocarbon	45	75
Miscible - CO_2	45	70
Thermal	40	70

Table 2.16 - Recovery Rates for Canadian Mines 1971 (66)

Method	Recovery Percentage
Underground Mining	
Shrinkage	75-85(a)
Cut + fill	near 100
Open stoping	60-80(b)
Room + Pillar	30-90
Sublevel caving	90
Other caving	near 100
Surface mining	
All methods	85-100

Notes (a) At depths greater than 750 m
(b) At depths less than 600 m

Table 2.16 shows extraction efficiencies for various mining methods in Canada for 1971. It can be seen that extraction efficiencies vary greatly, both within a mining method and between mining methods. There is less room for improvement in mining than in petroleum, but these improvements may become significant in future years.

In addition, a limit to extraction efficiency must arise through the energy requirement to crush and grind ore prior to beneficiation. Thus for a 2.5% ore body, one tonne of mineral involves the crushing of an additional 39 tonnes of gangue. Decreasing the ore grade to 0.25% and the gangue increases to 399 tonnes which is the main reason for the steep rise in Chapmans energy curve for copper presented in Section 2.4.2.

2.6.2 More Efficient Use of Resources

In the twentieth century there has been a vast development in the range of materials and processes available for the manufacture of goods. This is typified by the fact that both plastics and aluminium, which were of purely academic interest at the beginning of the century, are now being used in enormous quantities. The changes taking place are not only quantitative but are associated with radical changes in technology in the range and nature of processes available to the engineer enabling new methods of making, shaping, joining and finishing new and traditional materials to be used. These new methods allow the quantity of material used to be minimised to a level consistent with the finite nature of resources. This reduction in material demand may be achieved in three ways.

(1) Design for minimal use of material per unit produced.

(2) Product lifetime extension.

(3) Substitution of less scarce materials for scarce ones.

2.6.2.1 Design for Minimal Use of Material per Unit Produced

In section 2.5.3 the example of changes in the design of tin cans was quoted as potential for increased recycling effort. It is true however, that the increasing price of tin plays a significant part in design change policy, a trend which can be found in most products as manufacturers attempt to reduce production costs. While not a direct consequence of concern over world reserves of materials, such design changes do have the required effect of minimal use of material per unit output and the trend is expected to continue as consumers demand a product which carries out a task at minimum cost. In contrast, the producers needs are for a product which has a certain planned obsolescence so guaranteeing a future market. Changes in the "consumer needs - producers requirements" interface are slow and little change in the short term is anticipated although policy decision could affect it in the long-term. Much attention has been paid to the selection of materials and engineering design, the issues involved being well reviewed by Pickering (69) and Appoo (70) both of whom concluded that if materials are to be conserved it is important that the physical properties of a materials should be utilised to this maximum so that less material is used.

Henstock (71) points out that the trend towards the use of less material is at the expense of increasing structural complexity and that this results in a conflict between complex design, which saves materials, and the design of components in a form suitable for recycling. Specialised work in this area is necessary to identify the optimum use of material and is not discussed further here.

2.6.2.2 Product Lifetime Extension

One frequently proposed solution to material shortages is to increase the durability of products by engineering design. Many modern goods are designed for early disposal both to reflect rapidly changing consumer demand and to increase sales and profits.

The effect of extending product life can be shown with the aid of a simple example. If a constant increase in demand of 100 units per year is assumed with an average product life of two years then the pattern of annual demand is as shown by the solid line in Figure 2.16. If product life is extended to four years then the dotted line in Figure 2.16 is produced. Over an arbitrary period of twelve years annual demand for the goods with a life of four years is 50% of that for the goods with a two year life. More important, the cumulative demand is calculated to be 43% less for the goods with a life of four years.

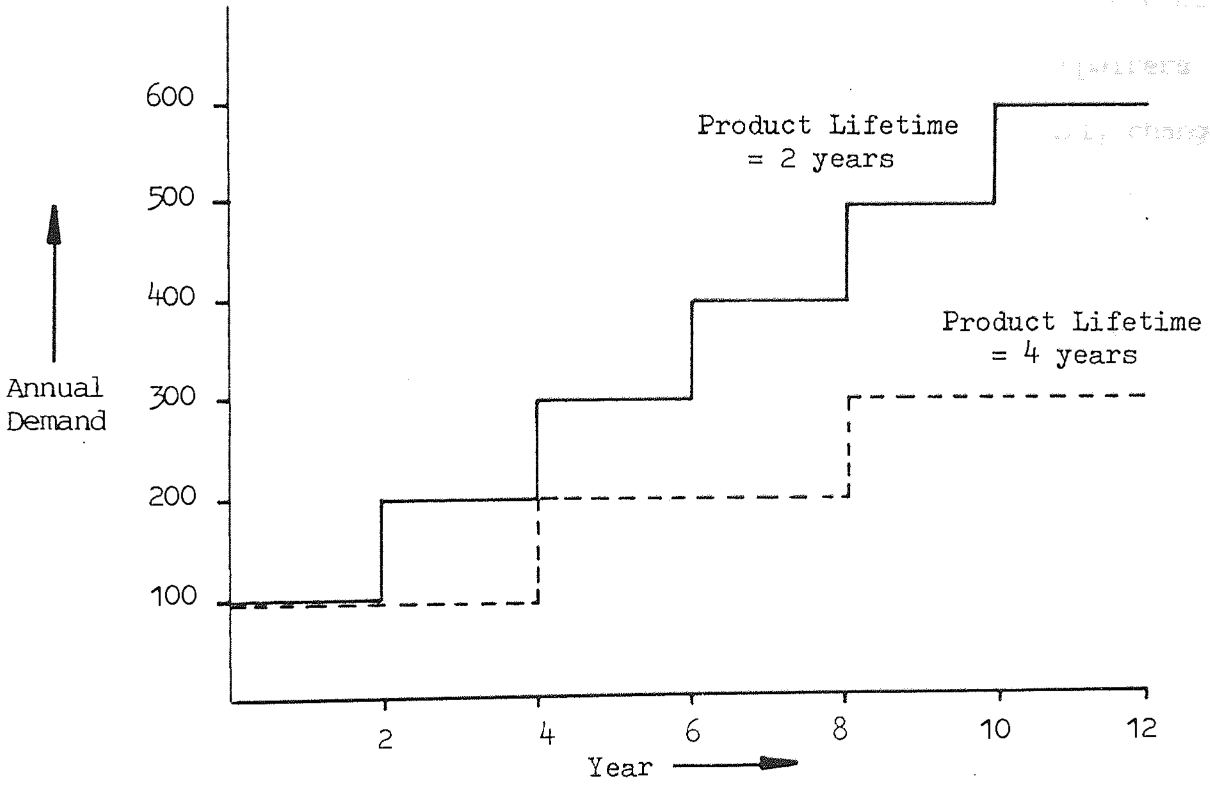


Figure 2.16 - Effect of Product Life extension Upon Demand

Although Figure 2.16 provides an example of the effect of product life extension, its potential contribution to resource conservation is largely unexplored. The US Environmental Protection Agency (EPA) in 1975 made simple calculations to estimate the effect of product life extension on car tyres and cars in the US (72). Based upon the assumption that original equipment tyres purchased after 1978 were to last for 100,000 miles compared to typical current values of 30,000 miles, and if all tyre replacements were retreaded 100,000 mile tyres that would last for another 27,000 miles, then tyre (and hence rubber, steel etc.) consumption would be reduced by 143 million tyres per year by 1990 so saving 23 million barrels of oil, 1.75 million tons of rubber and 525 million pounds of carbon black together with reduced environmental impact from tyre manufacturers.

Having established that product life extension does have potential for resource savings, how can extensions be introduced? Conn (72) considers that the physical durability built into a product is not the major determinant of a products lifetime. Actions by consumers, distributors and repairers must not be overlooked, indeed their attitudes must be fundamentally changed before manufacturers will consider extending product lifetimes. These changes in attitudes will take a long time to develop, particularly as extending product lifetimes will not be cost free. A German study quoted by Conn (73) showed that the use of higher quality materials required to double the life expectancy of a car to 20 years or more would cause a 30 per cent cost increase.

The problems of product lifetimes and their assessment are discussed generally by Conn (73) and will be examined in more detail for copper in Chapter 8.

2.6.2.3 Substitution

The concept that most materials can be substituted in various ways and that no material is therefore absolutely essential has attracted support (7,19). The market mechanism is expected to operate along the following lines. Firstly, the price of a commodity would rise as supplies became scarce, so limiting demand with the balance of demand being obtained from other materials i.e. substitute materials.

The possibilities of substitution between materials are extensive, in fact so extensive that care has to be taken. For example, sheet copper can be substituted by aluminium which could reduce demand for soldering agents such as tin and lead. Rajaraman (7) offers a partial list of substitutes for tin and lead which includes zinc for lead but lead and zinc are so commonly found together that some sources treat the two together for demand and pricing purposes. Substitution in this case is limited by the risk that both metals would become scarce simultaneously. Roberts (74) presents sources which argue for a similar interdependence between copper, lead, tin and zinc. To date, there is no evidence of a neat phasing of substitutes so that as one reserve 'runs out' another becomes available. There is a possibility that complete sets of raw materials, substitutable amongst themselves e.g. zinc and lead will become depleted at approximately the same time and in this case another set of materials, for example organic for inorganic, would be substituted.

Substitution is not a straightforward process but has considerable lead times which may be sufficient to cause disruption to an economy. Substitute materials may have the side effect of causing more pollution or requiring a higher energy input per unit produced. In the case of biomass substitutes, a reversal in historic trends in land use would be necessary. Table 2.17 lists some potential substitutes for metals in common use. It should be noted how often plastics appear and it is expected that other raw materials, such as high strength fibres, composites and ceramics, will be added to the list as their lead time for development is reached.

Table 2.17 - Principal Substitutes for Materials (20)

Material	Principal Substitutes
Aluminium ore (bauxite)	Kaolinite, dawsonite, alumite syenite, saprolite, coal ash.
Chromium	Nickel, Molybdenum, vanadium
Cobalt	Nickel
Copper	Aluminium, plastics
Lead	Rubber, copper, plastics, tile, titanium, zinc
Molybdenum	Tungsten, Vanadium
Tin	Aluminium, plastics
Tungsten	Molybdenum
Zinc	Aluminium, plastics

While substitution offers an alternative to recycling it is possible that the side effects of interrelationships of substitutes, environmental impact and production energy levels will make substitution of limited application. A comprehensive study investigating these interrelationships is outside the scope of this project although reference to the mechanisms of substitution will be made in later chapters with particular reference to copper.

2.6.3 Future Growth Patterns in Demand

Turning to the assumption of exponentially rising growth in consumption evident from section 2.2.4.2, and on the continuation of this growth which was the cornerstone of Meadows' world model there may be scope for change.

The statistician Quetelet and the mathematician Verhulst in the 1830's suggested that the 'S-shaped' or logistic curve is more probable than the exponential curve of Malthus for describing growth patterns within a closed system, such as the Earth, in which the curve threatens to hit a ceiling.

Figure 2.18 shows growth curves with respect to time according to exponential and S-shaped or logistic patterns. Projections based on exponential growth may be reasonably good for the time span to the inflection point, after which they can become absurd. The figures in this thesis show that pure logistic curves are unusual, but that curves that approach the S-form by way of platforms seem to be more common. Generally for mineral demand, the period 1870-1910 and 1950-1970 show a strong expansion while the period 1910-1950 for many minerals was a period of stagnation.

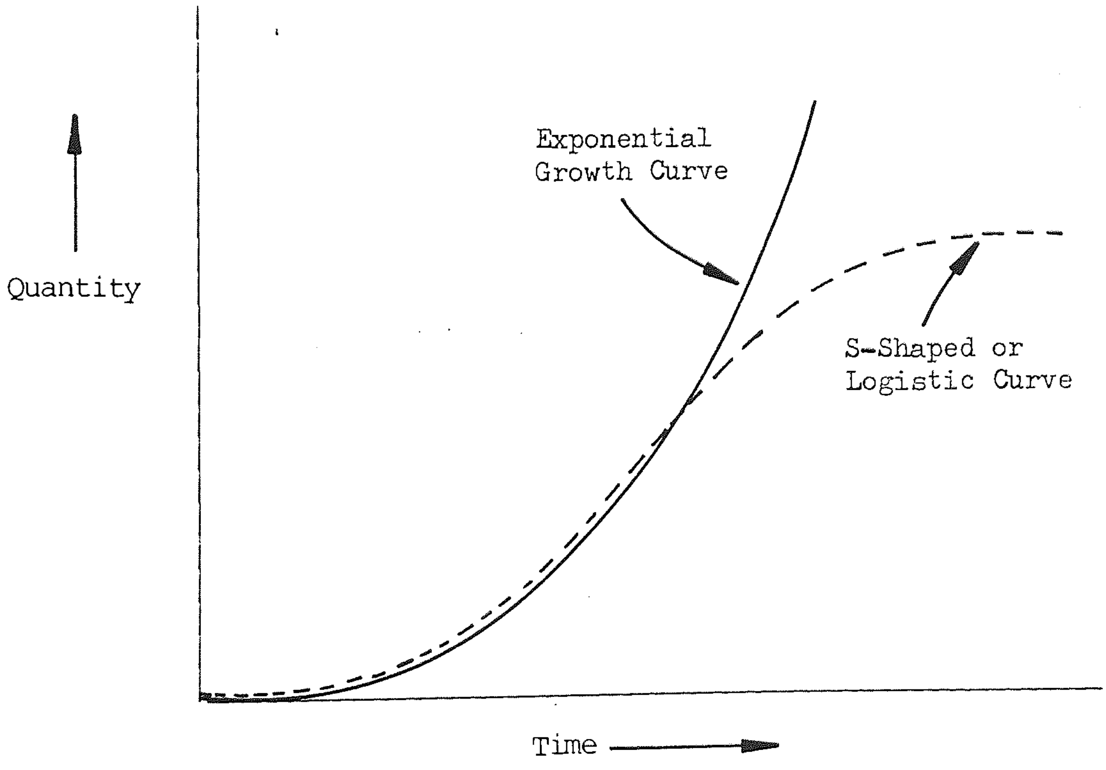


Figure 2.18 - Relationship Between Exponential and S-shaped or Logistic Growth Curves

Figure 2.19 presents two curves for copper and lead showing the relation between global consumption in kilograms of metal per capita and GDP per capita. If the two extreme right hand points are accepted as evidence of saturation effects at high GDP per capita then an S-shaped logistic curve can be fitted implying that the metal required per capita levels despite continuing growth in GDP per capita.

Attempts to estimate long term growth patterns for various economies must be tenuous and reference should be made to Malenbaum (75), Brookes (76) and Felix (77) for further discussion.

Using Figure 2.19 and UN population growth forecasts (78) then an estimate of future annual metal demand can be made as shown in Figure 2.20. The prediction shows a continuing exponential growth in world demand beyond the limits of Figure 2.20 due in the main to the economic development of less developed countries.

This method does not take into account constraints such as scarcity of metals, excessive price rises, substitution and recycling which would tend to shift the S-curve in Figure 2.19 downwards. Nor does it allow for a logistic curve for population. The United States Bureau of Mines (13) presents estimates which do include these factors but not the method used to determine them.

It would appear that S-shaped or logistic curves do represent the real world more closely than exponential growth curves but that little consolation can be derived from this unless population growth also follows a logistic curve and less developed countries do not develop economically at a pace which cannot be met by substitution and recycling effort in developed countries.

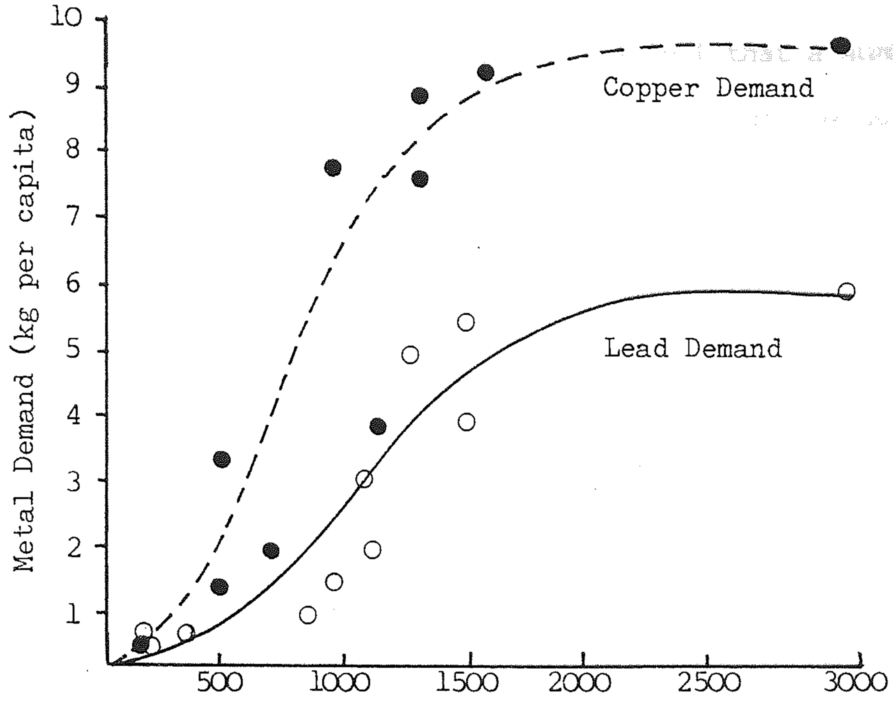


Figure 2.19 - Metal Demand per Capita v Economic Growth (79)

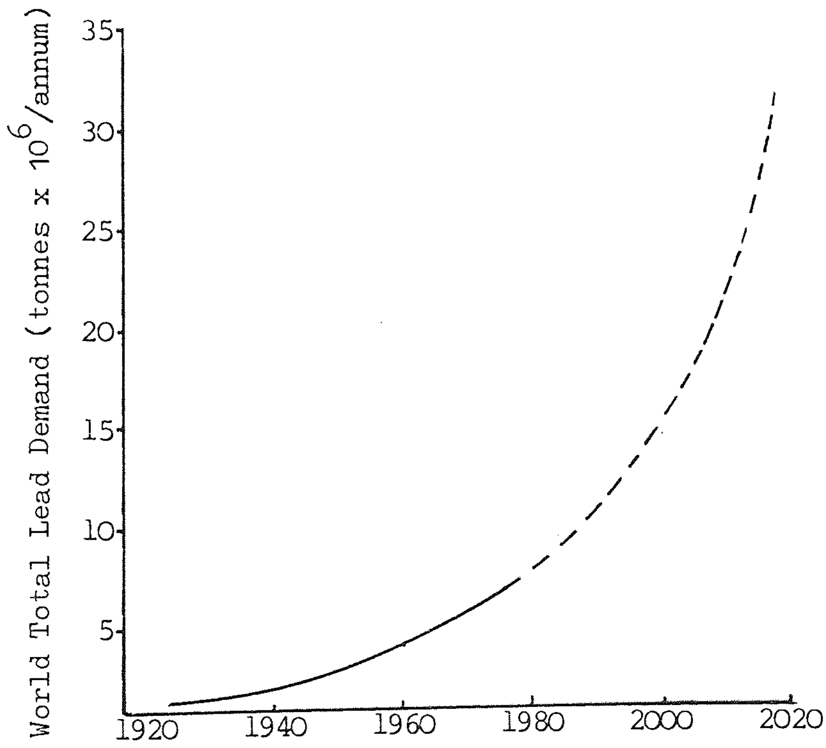


Figure 2.20 - Predicted Growth Rate in Lead Demand (79)

2.7 Summary of Chapter 2

Owing to the complex nature of the topics discussed in chapter 2 and the interrelationship of these topics it was felt that a summary of the major conclusions arrived at during this chapter would be useful.

In the first part of this chapter the definitions and problems of the estimation of reserve and resource size were examined together with the adequacy of these reserves to meet an apparently exponential growth in consumption. It was concluded that if historic exponential trends were to continue then it is unlikely that future reclassification of resources as reserves would be capable of satisfying consumption.

In order to assess the effect of this conclusion, the generalised flow of materials through an economy were described with particular care being devoted to definition of terms. Recycling was identified as a possible solution to the dilemma of lack of resources identified above.

The advantages and disadvantages of recycling were then examined with the major benefits being energy savings, lower investment costs, a reduced volume of waste for disposal, a benefit to the Balance of Payments and a strategic supply of raw materials. Possible disadvantages could be inreased pollution due to increased activity as much processing is currently carried out before importation and a reluctance by consumers to participate in a society with an increased level of recycling. The effect of recycling upon the time to exhaustion of resources was found to be dependent upon the assumptions surrounding future growth patterns in consumption.

A need was found to equate the private and social costs of recycling through fiscal measures and engineering design with a brief discussion on each topic being given.

Finally the alternatives to recycling were investigated. Increased extraction efficiency was found to be possible, but as in the case of conversion of resources to reserves, little effect would be found in the face of continuing exponential growth. More efficient ways of utilising materials were examined with product life extension offering the best hope although substitution and product design have a role to play. Future growth patterns were then examined and it was concluded that exponential growth patterns would continue unless the developed countries were prepared, through the mechanisms of recycling, substitution and engineering design, to reduce their per capita consumption of materials so that the less developed countries could progress towards competitive economies which require an increase in per capita material consumption.

Only if these criteria are met will the doomsday predictions of Meadows be avoided and recycling has an important part to play in the U.K. contribution to the solution. Having examined all these complex areas, it is not possible to investigate their effects upon all materials and certain materials need to be selected for a more detailed examination. The next chapter will allow the significance to the U.K. of various materials to be examined and enable the selection of materials worthy of investigation.

CHAPTER 3 - SELECTION OF MATERIALS OF SIGNIFICANCE TO THE UNITED KINGDOM

3.1 Introduction

In Chapter 2 the global situation with reference to the long term availability of natural resources was examined together with an assessment of the methods available to minimise the time to "exhaustion" of these resources.

The United Kingdom (U.K.) as an industrialised trading nation is concerned with resource exploitation as it has few natural resources of its own. This lack of indigenous raw materials affects the U.K. in two ways. Firstly the effectiveness of the U.K.'s trading position is largely dependent upon raw materials whose price is governed by supply and demand relationships operating outside the U.K. The supply and demand position also affects foreign markets for U.K. produced goods. Secondly a heavy reliance upon imported raw materials makes the U.K. particularly vulnerable (industrially and strategically) to restrictions in supply. These restrictions may be natural, as in the exhaustion of a mine or political as in the Yom Kippur war in 1973.

Many studies have been carried out on how the U.K. can, through recycling and other methods, reduce its reliance upon imported materials. Generally, these studies have been very narrow in their view and have concentrated on particular materials and/or industries, e.g. oil, coal, aluminium, glass and domestic refuse, with little objective regard to the importance of the material to the U.K. or to the significance of a change in exploitation or recovery patterns. The studies carried out on these broader aspects have been instigated by high level government or military authorities and so have a very limited circulation.

In this chapter, the most important materials to the U.K. will be identified. This will aid determination of where research effort should be directed at improving the utilisation and recovery efficiencies to offer the greatest advantage.

3.2 Methodology

The importance of a material depends upon the viewpoint of the assessor so that what is "important" to an industrialist may differ from what is "important" to a government official. This makes it difficult both to measure importance and to compare the importance of one material to another. The method employed in this work is based upon the weighting-factoring method. The procedure followed involves these basic steps:-

1. List all materials/resources to be considered.
2. List all criteria which may be relevant to the evaluation of "importance" to the U.K.
3. Select the relevant criteria.
4. Quantitatively rank each material for each criterion to give a "score" or factor.
5. Weight the criteria according to their relative importance.
6. Sum the product of factors and weightings to give a total "score".
7. Carry out a sensitivity analysis to compare the effect of different weightings.

By using this method, the viewpoint of the industrialist or politician may be obtained by suitable weighting of the criteria. The scope of this exercise is very large and the limits on facilities available meant that some simplifications and assumptions had to be made. These are identified and justifications provided when relevant.

3.3 Materials Considered

Materials flows in the U.K. are very complex in that materials may enter or arise as raw materials or feedstocks in a range of grades, or as imported semifinished or finished goods; undergo a sequence of transformations; and be consumed or discarded internally or leave the U.K. in a wide range of products.

One approach to clarification of materials is to consider inter-industry flows where the various major industrial sectors are defined and the flows of materials to and from other sectors (at home and abroad) are considered. This is the basis of the Standard Industrial Classification (SIC) system.

The SIC was first issued in 1948 to "promote uniformity and comparability in official statistics of the U.K" and in a revised edition follows the same general principles as the International SIC of all Economic Activities used by the U.N.

The classification is arranged under a list of industry headings which show the minimum detail in which statistics by industry will normally be provided and which are therefore called "Minimum List Headings" (MLH). The MLH's of related industries are also grouped into ORDERS. Overall, the SIC consists of 181 MLH arranged in 27 orders. Optional subdivisions of the MLH are available.

However, the SIC is concerned with <u>all</u> U.K. industries and is too comprehensive for this project; materials may be included under several MLH making the abstracting of data difficult. Certain MLH, such as Street Musicians and Cream Cake Manufacturers, may be ignored on grounds of irrelevance which does help to simplify the system. However, the SIC is complex, difficult to interpret and materials may be included under several Minimum List Headings making data abstraction difficult.

The alternative classification is by elements and their derivatives which is more definitive and compact in terms of data collection. This approach was chosen after preliminary examination of both classifications as providing the simplest and most directly useful and usable system. It will also enable direct comparison to be made with other work. The only exception is the petrochemical and fossil fuel industries when classification under carbon would have been unhelpful and coal, natural gas, petroleum (oil) are considered separately. Finally, seven particularly rare materials were excluded such as astatine and francium. A full list of materials covered is given in Table 3.1. Each entry includes that element and its derivatives and compounds, using natural industrial relationships for differentiation. For example, hydrochloric acid is included under chlorine rather than hydrogen and phosphoric acid under phosphorus rather than oxygen. Difficult cases were dealt with arbitrarily.

Table 3.1

LIST OF MATERIALS CONSIDERED

Aluminium
Antimony
Argon
Arsenic
Barium
Beryllium
Bismuth
Boron
Bromine
Cadmium
Caesium
Calcium
Carbon
Chlorine
Chromium
Cobalt
Copper
Fluorine
Gallium
Germanium
Gold
Hafnium
Helium

Hydrogen
Indium
Iodine
Iron
Krypton
Lead
Lithium
Magnesium
Manganese
Mercury
Molybdenum
Neon
Nickel
Niobium
Nitrogen
Oxygen
Phosphorus
Platinum Group
Potassium
Rare Earths
Rhenium
Rubidium
Selenium

Silicon
Silver
Sodium
Strontium
Sulphur
Tantalum
Tellurium
Thallium
Thorium
Tin
Titanium
Tungsten
Uranium
Vanadium
Xenon
Yttrium
Zinc
Zirconium

Coal
Natural Gas
Petroleum

3.4 Criteria

A comprehensive list of as many criteria as possible that may influence the use and/or development of any resource was drawn up under three general headings (Table 3.2). The first heading, economics, includes criteria which reflect the importance of a material to the U.K. at both macro and micro-economic levels for virgin and secondary materials. The criteria under the second heading, quantities, illustrate the physical size of the industries dealing with that material. By jointly considering the criteria under these two headings it is possible to cater for the low volume (quantity criteria), high value (economics criteria) materials.

The third heading, availability, includes criteria which assess the potential and future supply of the materials considered, together with the potential for increases in U.K. indigenous supply from secondary sources.

3.5 Criteria Selection and Evaluation

Many of the criteria in Table 3.2 are duplicated or closely interrelated with criteria under other headings. For example, the percentage of consumption from U.K. production is included under the economics and quantities headings as criteria numbers 9 and 25. Criteria interaction is very complex and coherent illustration is difficult and of limited practical value. Instead, Figure 3.1 shows the more well established relationships between the criteria in Table 3.2 although in some cases the criteria listed are a combination of other criteria and cannot be illustrated directly. As the major aim of this exercise is to develop a quantifiable method for assessing significance, factual data are preferred in order to be objective in the factors assigned to relative importance. Subjective assessment may alternatively be employed when specific data are not available, but these are largely based on opinion and to a certain extent intuition and are, therefore, less reliable. As all the criteria are interrelated, the criteria weightings employed in the computation of importance may be used to simulate subjective opinions in certain criteria.

The original 62 criteria may thus be reduced by avoiding duplication, employing derivatives of several criteria, for example import value from

Table 3.2

CRITERIA THAT AFFECT THE SIGNIFICANCE OF RESOURCE CONSUMPTION

Economics

1 Operating costs of primary production
2 Capital costs of primary production
3 Operating costs of secondary production
4 Capital costs of secondary production
5 Effect of raw materials grade upon 1 -4
6 Current rate of investment in 1 -4
7 Consumption value
8 Production value
9 Percentage of consumption from UK production
10 UK import value
11 UK export value
12 Balance of payments
13 Price/unit
14 Stability of price/unit
15 Effect of current recycling practice upon balance of payments
16 Effect of increasing recycling practice upon balance of payments
17 By-co-main product (status of product in the manufacturing industries)
18 Effect of increased substitution
19 Effect of changes in growth rate
20 Number of suppliers
21 Nature of suppliers
22 Currency parity with suppliers

Quantities

23 Consumption quantity
24 Production quantity
25 Percentage of consumption arising from UK production
26 Percentage of consumption arising from UK reserves
27 Actual recycle
28 Potential recycle
29 UK losses
30 Ratio of actual to potential recycle
31 Effect of increased recycle
32 Usage per capita compared to world average
33 Import quantities
34 Export quantities
35 Nett flow of quantities
36 Percentage of consumption arising from imports
37 UK growth rate
38 World growth rate
39 Comparison of UK and World growth rates
40 Effect of UK growth rate upon trade quantities
41 Extent of substitution
42 Environmental effects of primary production
43 Environmental effects of secondary production
44 Form of final products
45 Geographical location of suppliers

Availability

46 Demonstrated reserves
47 Inferred and potential reserves
48 Static life index using demonstrated reserves
49 Exponential life index using demonstrated reserves
50 Static life index using inferred reserves
51 Exponential life index using inferred reserves
52 Demonstrated reserves in the UK
53 Inferred reserves in the UK
54 Geographical location of raw material suppliers
55 Stability of suppliers
56 Effect on stability of changes in grade of raw material
57 Renewable or non-renewable resource
58 Actual recycle
59 Potential recycle
60 Ratio of actual to potential recycle
61 UK losses
62 World growth rates

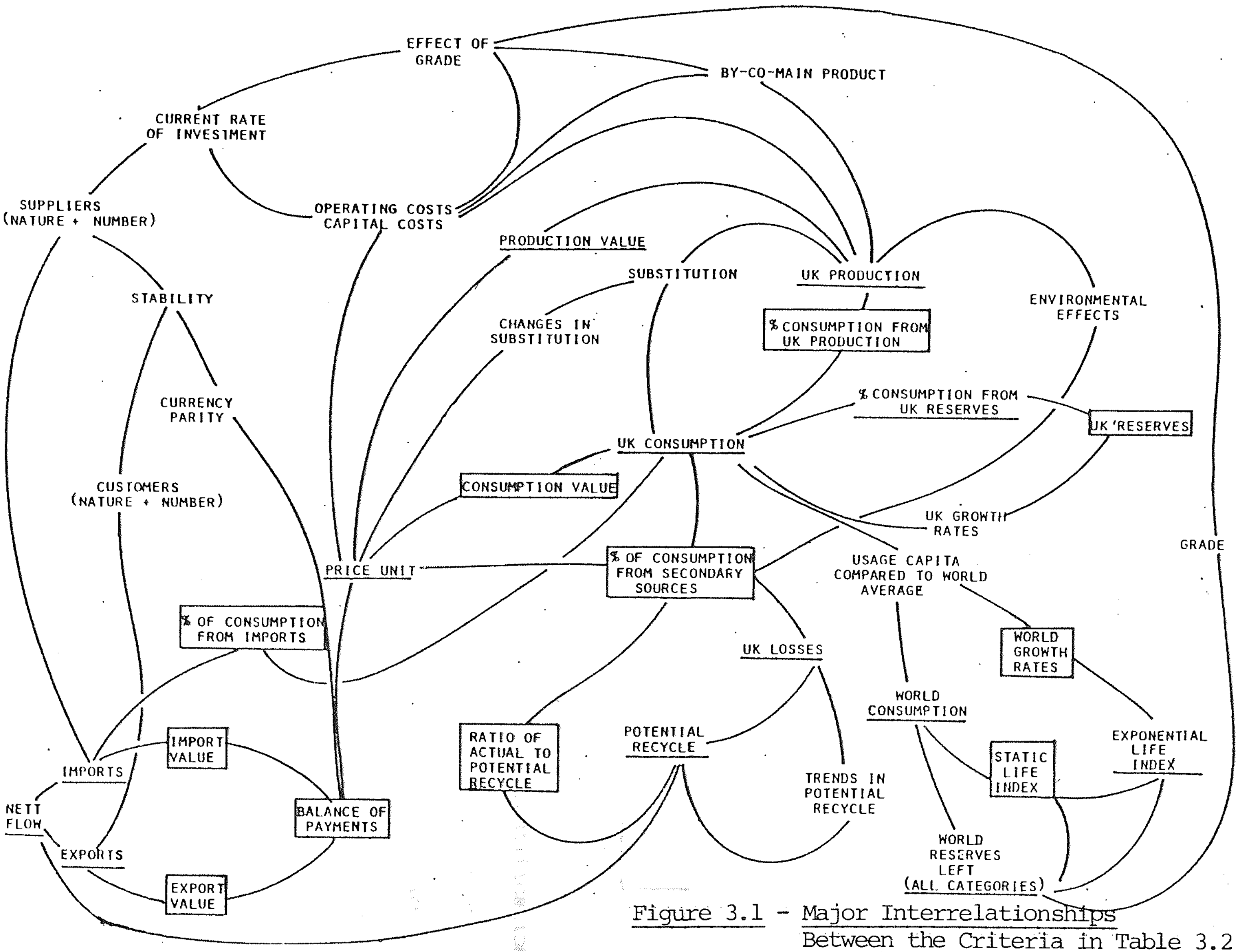


Figure 3.1 - Major Interrelationships Between the Criteria in Table 3.2

price per unit and import quantity, and restricting assessment to those criteria which may be objectively measured. This leaves the 11 criteria listed in Table 3.3. These may also be grouped under the three main headings of economics, quantities and availability and are related as shown in Figure 3.2.

Table 3.3

FINAL LIST OF CRITERIA TO BE CONSIDERED

Criterion Number	
7	Consumption value (economic, quantities)
10	Import value (economic)
11	Export value (economic)
12	Balance of payments (economic)
25	Percentage of consumption from UK production (quantities)
27	Actual recycle (quantities, availability)
30	Ratio of actual to potential recycle (availability)
36	Percentage of consumption from imports (quantities)
38	World growth rates (quantities)
48	Static life index (availability)
52	UK reserves (quantities, availability)

3.6 Ranking Procedure

The eleven criteria listed in Table 3.3 are capable of quantification to provide a numerical indication of their relative importance. In order to indicate the overall importance of the material in question points are awarded to each element in respect of the value of each criterion and then to sum the criteria points for each element.

It was decided that, for convenience, the points awarded should vary between zero and one hundred, such that if no data were available a zero value would automatically be applied. No other satisfactory average or mean could be applied although it is appreciated that distortions could arise if the number of criteria for which data are available varied between the materials considered.

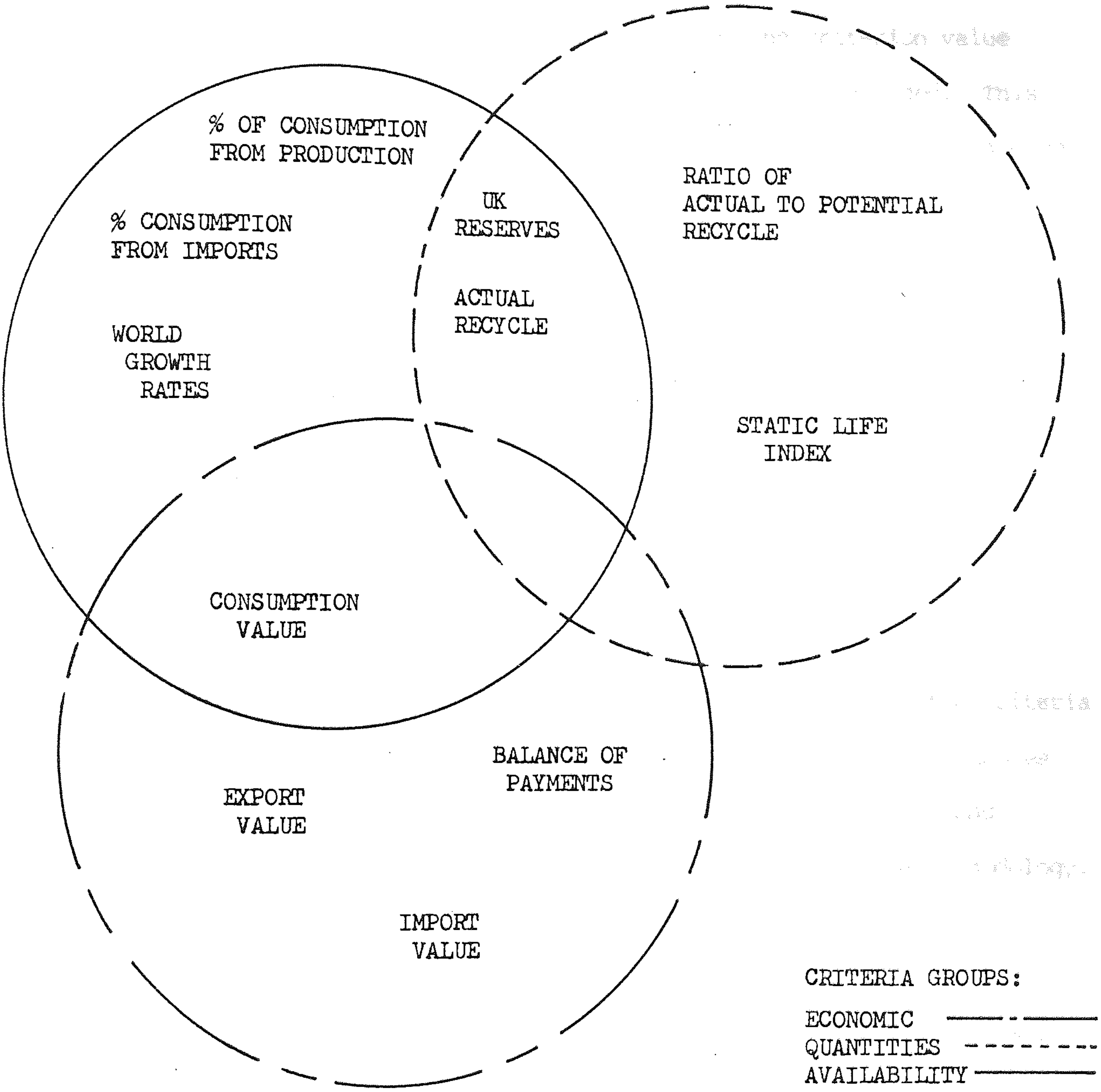


FIGURE 3.2 - DIAGRAM SHOWING THE BROAD INTERRELATIONSHIPS BETWEEN THE SELECTED CRITERIA IN TABLE 3.3

A logarithmic scale, analogous to the measurement of noise levels in dB, was employed, so that a doubling or halving of the criterion value results in a ten point increase or decrease in the points awarded. This was chosen due to the unusual distribution of data, when a linear scale would have produced extremes of points near to 100 or near to zero. The procedure was to normalise the data between 0 and 100, take logs, then re-normalise from 0 to 100. The computer flow diagram for carrying out the whole exercise is shown in Figure 3.3. Points for each criterion may be added in an analogous way to that for noise levels, and thus a material with a score of 60 would be considered twice as important as a material with a score of 50. For example, phosphorus, aluminium and fluorine with SLI's of 1909, 106 and 22 years respectively will be awarded 20, 62 and 85 points as they lie between gold (8 years SLI, 100 points) and gallium (25000 years SLI, 0 points).

Similarly, it would be a relatively simple task to alter the criteria value of selected elements in order to investigate the effects of changes in certain areas, for example, a decrease in imports of petroleum and natural gas because of North Sea Oil, thus providing a flexible methodology.

3.7 Weighting Procedure

Although the points awarded for each of the eleven criteria detailed in Table 3.3 indicates the overall significance of a material, the application of a weighting factor to selected criteria, or groups of criteria, permits the investigation of areas of particular interest. For example, the effect of an increase in the balance of payments criterion may be examined by the application of a suitable weighting factor to that criterion. Similarly a suitable weighting factor, applied to each of the three criteria sub-groups, identified in Figure 3.2 and listed in Table 3.4, assists in the interpretation of their relative significance.

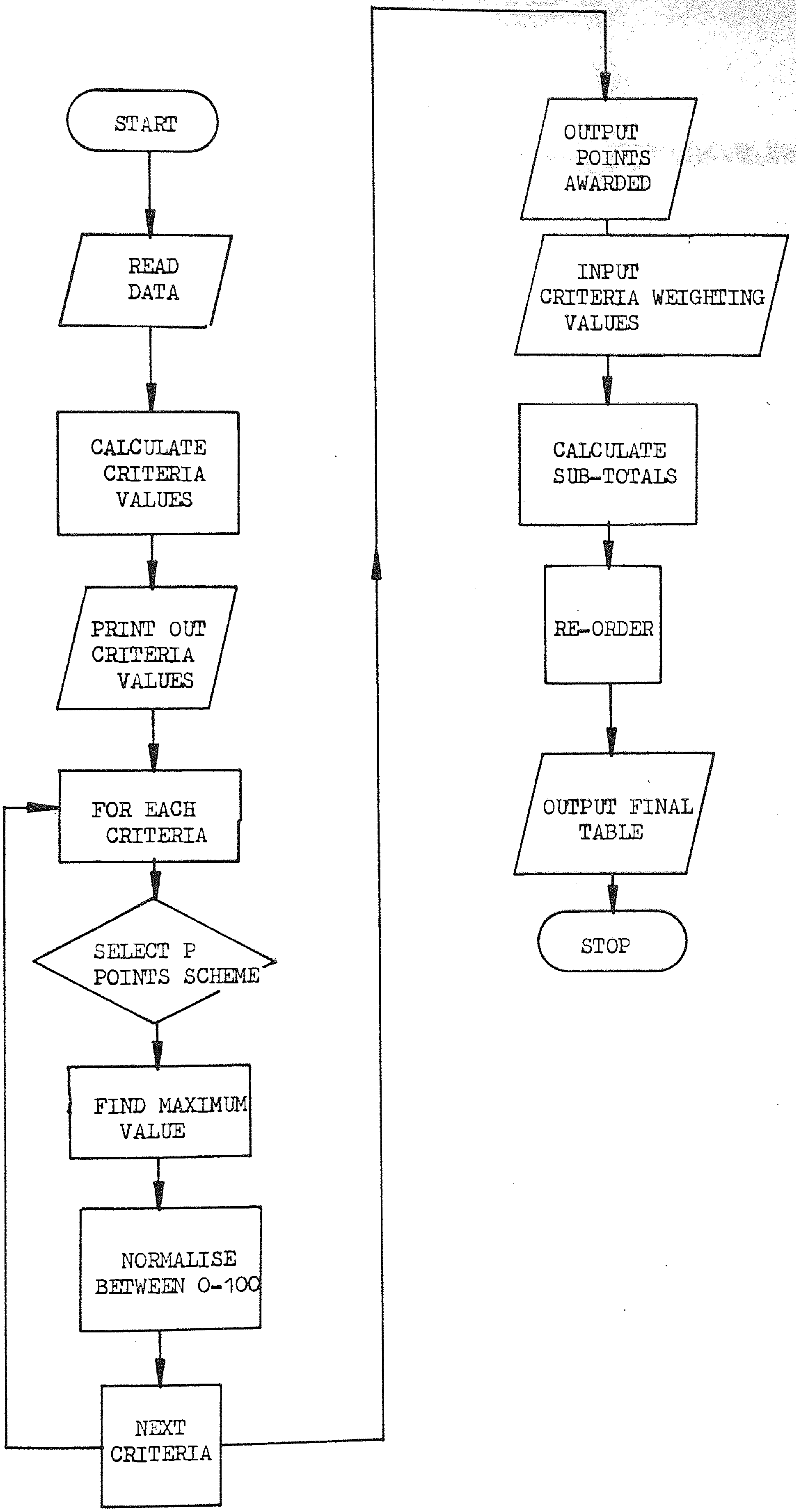


FIGURE 3.3 - COMPUTER FLOWCHART OF PROGRAM TO CALCULATE THE SIGNIFICANCE OF MATERIALS TO THE UK

Table 3.4

Table Showing the Order of the Application of Weighting Factors for use with the Results Tables

Criteria from Table 2	Criteria	Sub-group
7	Consumption value)	
10	Import value)	ECONOMIC
11	Export value)	
12	Balance of payments)	
25	Percentage of consumption from UK production)	
36	Percentage of consumption from imports)	QUANTITIES
38	World growth rates)	
52	UK reserves)	
27	Actual recycle)	
48	Static life index)	
30	Ratio of actual to potential recycle)	

Typically, a weighting of two, three or four times might be employed. As the scales are logarithmic, doubling importance is achieved by adding ten points and four times by adding twenty points. It turned out that this would have had no effect on the final results, and instead the traditional two times factor was employed which effectively squares the effect of the appropriate criterion or group of criterion, and can be considered as an extreme weighting value. Any weighting factor between zero and two (or above) may be applied. A zero weighting factor has the effect that the criterion or group of criteria is not being considered; a value of one indicates that the points awarded are the same as in the unweighted case. A value higher than one indicates that the criterion or sub-group is being awarded a special significance.

3.8 Calculation of Significance Level

The total or final 'score' is calculated by summing the weighted criteria points for each element.

For ease of interpretation the final scores are re-arranged into numerically descending order, as shown later in Table 3.8.

A sensitivity analysis has been carried out using modified criteria values and weightings with the top twenty elements only being listed for ease of comparison.

3.9 Criteria Values used in the Calculation of Significance Level

The criterion values employed in this exercise are shown in Table 3.5 and are derived from two main sources (13,80). The internal self-consistency of the sources reduced problems of data incompatibility to a minimum.

The materials with the highest consumption values are the energy sources, petroleum and coal, followed by copper and this pattern is reflected in the balance of payments criteria for petroleum and copper where large import values are not matched by export values. Iron is the only material with a significant beneficial surplus of export value over import value although gold has both a large import and export value. The majority of the materials considered rely heavily upon imports to satisfy consumption, some exceptions being antimony, iron, natural gas and coal, although the consumption from UK production criterion shows that these imports are often in the form of raw materials or unfinished goods. Turning to the availability criteria the SLI values have already been discussed (Section 3.6) where it was noted that gold with an SLI of 8 years and gallium with 20,000 years are the extremes, with most industrially important materials lying in the 50-100 years range. Growth rates varied between 10.1% for uranium to 1.3% for

Table 3.5 - Values of the Criteria Listed in Table 3.3

ELEMENT	CONS VALUE	UK RESERVES	GROWTH RATE	(BY-CO PRODUCT)	IMPORT VALUE	EXPORT VALUE	ACTUAL RECYCLE	S.L.I.	B.O.P.	% CONS FROM UK PRODUCTION	RECYCLE RATIO	% CONS FROM IMPORTS
AL	361840	1	63	100	113	39	30	106	-74	71	15	82
SB	9987	1	20	30	8	3	55	59	-6	75	12	25
AR	n.a	1	46	50	n.a.	n.a.	0	large	n.a.	n.a.	n.a.	n.a.
AS	n.a.	1	19	10	0	0	0	74	0	n.a.	n.a.	100
BA	n.a.	1	30	100	1	0	0	38	-1	n.a.	n.a.	100
BE	n.a.	1	50	30	1	0	n.a.	462	-1	n.a.	n.a.	100
BI	n.a.	1	15	10	1	1	2	25	0	n.a.	25	100
B	n.a.	1	43	55	3	1	0	105	-3	n.a.	n.a.	100
BR	n.a.	1	30	50	0	0	0	large	0	n.a.	n.a.	100
CD	7888	1	27	10	3	1	0	54	-2	18	n.a.	100
CS	n.a.	1	43	50	n.a.	n.a.	n.a.	20000	n.a.	n.a.	n.a.	n.a.
CA	27191	1	37	100	2	7	3	large	5	100	20	2
C	n.a.	1	n.a.	100	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
CL	n.a.	1	48	50	n.a.	n.a.	5	large	n.a.	n.a.	14	n.a.
CR	5894	1	27	100	9	3	5	414	-6	n.a.	14	72
CO	2040	1	16	10	4	2	7	108	-2	n.a.	17	100
CU	660000	1	46	100	213	84	37	53	-129	37	10	69
FL	n.a.	1	47	100	3	3	1	22	0	n.a.	10	100
GA	n.a.	1	26	100	n.a.	n.a.	n.a.	25000	n.a.	n.a.	n.a.	n.a.
GE	n.a.	1	20	10	1	0	50	32	-1	n.a.	12	100
AU	n.a.	1	32	80	303	320	95	8	16	n.a.	10	100
HF	n.a.	1	33	10	n.a.	n.a.	n.a.	5620	n.a.	n.a.	n.a.	n.a.
HE	n.a.	1	41	10	n.a.	n.a.	0	n.a.	n.a.	n.a.	n.a.	n.a.
H	n.a.	1	86	55	n.a.	n.a.	0	large	n.a.	n.a.	n.a.	n.a.
IN	n.a.	1	15	10	n.a.	n.a.	n.a.	37	n.a.	n.a.	n.a.	n.a.
I	n.a.	1	36	30	1	0	0	large	-1	n.a.	n.a.	100
FE	284400	1	20	100	256	394	50	233	137	100	11	19
KR	n.a.	1	n.a.	50	n,a.	n.a.	0	large	n.a.	n.a.	n.a.	n.a.
PB	105700	1	21	100	34	34	55	28	1	85	11	88
LI	n.a.	1	43	100	n.a.	n.a.	n.a.	1285	n.a.	n.a.	n.a.	n.a.
MG	91600	1	47	100	11	5	15	509	-6	100	13	55
MN	18700	1	28	100	16	0	10	93	-15	n.a.	15	71
HG	n.a.	1	26	100	2	1	45	13	- 2	n.a.	12	100
MO	12145	1	41	10	9	1	3	74	-8	n.a.	20	100
NE	n.a.	1	n.a.	50	n.a.	n.a.	0	large	n.a.	n.a.	n.a.	n.a.
NI	62181	1	34	100	82	63	20	139	-19	100	15	100
NB	1799	1	51	75	2	1	2	1316	-1	n.a.	25	100
N	n.a.	1	49	50	n.a.	n.a.	0	large	n.a.	n.a.	n.a.	n.a.
O	n.a.	1	44	50	n.a.	n.a.	0	large	n.a.	n.a.	n.a.	n.a.
P	10803	1	51	100	31	13	0	1909	-18	96	n.a.	100
PT	n.a.	1	34	30	49	56	95	135	7	n.a.	10	100
K	8303	1	44	100	15	0	0	7615	-15	n.a.	n.a.	100
NG	305409	1	47	100	9	0	2	38	-9	97	30	2
RH	n.a.	1	49	10	n.a.	n.a.	0	240	n.a.	n.a.	n.a.	n.a.
RU	n.a.	1	33	10	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
OL	2176110	1	39	100	1166	219	2	31	-947	0	30	100
SE	n.a.	1	18	10	1	1	1	74	0	n.a.	30	100
SI	32186	1	34	100	21	2	0	large	-19	42	n.a.	99
AG	n.a.	1	21	75	14	61	95	20	47	n.a.	10	100
NA	n.a.	1	47	75	5	22	3	large	17	n.a.	13	100
ST	n.a.	1	31	100	n.a.	n.a.	n.a.	96	n.a.	n.a.	n.a.	n.a.
S	57068	1	43	10	24	9	5	69	-15	100	16	92
TA	n.a.	1	48	50	1	0	10	86	-1	n.a.	15	100
TE	n.a.	1	23	10	n.a.	n.a.	0	319	n.a.	n.a.	n.a.	n.a.
TL	n.a.	1	13	10	n.a.	n.a.	n.a.	55	n.a.	n.a.	n.a.	n.a.
SN	58500	1	13	100	38	25	30	16	-13	100	13	100
TI	1746	1	42	75	14	19	1	102	5	n.a.	100	100
W	21980	1	32	50	8	4	2	42	-4	0	20	94
V	2024	1	42	50	1	2	0	595	0	n.a.	n.a.	89
XE	n.a.	1	n.a.	50	n.a.	n.a.	0	large	n.a.	n.a.	n.a.	n.a.
Y	n.a.	1	47	30	n.a.	n.a.	n.a.	464	n.a.	n.a.	n.a.	n.a.
ZN	107708	1	28	75	42	6	25	487	-36	20	14	70
ZI	3308	1	33	30	1	0	2	73	-1	n.a.	20	100
C1	890125	1	41	100	57	15	2	2304	-42	99	30	4
TH	n.a.	1	99	30	0	n.a.	95	1979	n.a.	n.a.	10	100
U	n.a.	1	101	30	n.a.	n.a.	95	175	n.a.	n.a.	10	n.a.
RE	n.a.	1	40	100	0	0	n.a.	527	0	n.a.	n.a.	100

NOTES: 1) C1=COAL
OL=OIL
NG=NATURAL GAS
2) CARBON (C) NOT CONSIDERED
3) CONSUMPTION VALUE (CONS.VALUE): 1972 CONSUMPTION EXPRESSED INTHOUSANDS OF US DOLLARS USING A VALUE/UNIT FIGURE (13) AND UK CONSUMPTION DATA(80)
4) UK RESERVES: INCOMPLETE DATA HAS NECESSATIATED EXCLUSION OF THIS CRITERION. ARBITRARY UNIT VALUE ASSIGNED
5) GROWTH RATES: FROM (13) MULIPLIED BY FACTOR OF TEN
6) BY-CO-MAIN PRODUCT: SUBJECTIVE CRITERION; HIGH VALUE =MAIN PRODUCT; LOW VALUE = BY PRODUCT
7) IMPRT/EXPORT VALUES: 1972 VALUES(80) EXPRESSED IN £ MILLION
8) ACTUAL RECYCLE (RECYCLE): AS A % OF CONSUMPTION
9) STATIC LIFE INDEX (S.L.I.):CALCULATED FROM (13)
10) BALANCE OF PAYMENTS(BOP):CALCULATED FROM (80)
11) % CONSUMPTION FROM IMPORTS AND UK PRODUCTION: FROM (80)
12) RATIO OF ACTUAL TO POTENTIAL RECYCLE(RECYCLE RATIO): ACTUAL RECYCLE AS A PERCENTAGE OF POTENTIAL RECYCLE
13) n.a. = NOT AVAILABLE

tin averaging 3 to 4% per annum. Actual recycle rates for most industrially important materials are high varying from 95% for gold to 37% for copper and 10% for manganese. The potential for increased recycling averages 10 to 20% with the extremes being titanium (100%) and fluorine (10%).

Using data extracted from Table 3.5 and the computer package shown in Figure 3.3 points were awarded to each material for each criterion as shown in Table 3.6.

3.10 Base Run Results

A base run where the individual criterion were considered to be of equal significance i.e. a weighting factor of one was computed. The results are given in Table 3.7 where the subtotals of the three criteria groups are given together with the total points awarded. Table 3.8 is a modified version of Table 3.7 showing the final ranking of materials in descending order of importance. Table 3.8 shows that with all criteria weighted equally, the most significant material to the UK is copper which is awarded consistently high points in all the criteria considered. Copper is followed in descending order of significance by oil, iron, aluminium and nickel. The secondary position of oil is a result of the low points awarded in the percentage of UK consumption from UK production criterion, upon which the effects of North Sea Oil has not been incorporated. The third position of iron is mainly as a result of a lower Static Life Index.

Table 3.8 also shows the number of criterion considered in the ranking of each material and the points awarded per criterion. Those materials with a low number of criteria are predominantly the atmospheric and rare gases together with the less common materials. Uranium, because of its politically sensitive nature combined with its potential as a power source has a low number of criteria values but a high points/criterion value. Generally,

Table 3.6 - Points Awarded to each of the 11 Criterion Considered

ELEMENT	CONS.VAL.	RESERVES	GROWTH	BY-CO	IMP.VAL.	EXP.VAL.	RECYCLE	S.L.I.	B.O.P.	% CONS. FROM PROD.	RECYCLE RATIO	% CONS FROM IMPORTS
AL	74	100	93	100	66	67	83	62	63	95	73	97
SB	22	100	77	83	28	27	92	71	26	96	69	80
AR	0	100	89	90	0	0	0	0	0	0	0	0
AS	0	100	76	67	0	0	0	67	0	0	0	100
BA	0	100	82	100	3	0	0	77	6	0	0	100
BE	0	100	90	83	0	0	0	41	0	0	0	100
BI	0	100	72	67	2	14	44	83	0	0	80	100
B	0	100	88	91	16	9	0	62	15	0	0	100
BR	0	100	82	90	0	0	0	0	0	0	0	100
CD	19	100	81	67	13	16	0	72	8	75	0	100
CS	0	100	88	90	0	0	0	0	0	0	0	0
CA	37	100	85	100	9	41	50	0	23	100	77	44
C	0	100	0	100	0	0	0	0	0	0	0	0
CL	0	100	89	90	0	0	57	0	0	0	72	0
CR	14	100	81	100	29	28	57	42	27	0	72	95
CO	0	100	73	67	18	20	62	62	13	0	74	100
CU	83	100	89	100	75	78	86	72	71	85	74	95
FL	0	100	89	100	12	27	34	85	0	0	67	100
GA	0	100	80	100	0	0	0	0	0	0	0	0
GE	0	100	77	67	4	3	91	80	1	0	69	100
AU	0	100	83	97	81	97	100	100	41	0	67	100
HF	0	100	84	67	0	0	0	5	0	0	0	0
HE	0	100	87	67	0	0	0	0	0	0	0	0
H	0	100	98	91	0	0	0	0	0	0	0	0
IN	0	100	72	67	0	0	0	77	0	0	0	0
I	0	100	85	83	0	0	0	0	0	0	0	100
FE	71	100	77	100	78	100	91	51	72	100	68	76
KR	0	100	0	90	0	0	0	0	0	0	0	0
PB	56	100	77	100	49	65	92	82	0	98	68	98
LI	0	100	88	100	0	0	0	26	0	0	0	0
MG	54	100	89	100	33	37	73	39	27	100	71	91
MN	31	100	81	100	38	0	67	64	40	0	73	95
HG	0	100	80	100	9	6	89	93	8	0	70	100
MO	25	100	87	67	30	15	50	67	31	0	77	100
NE	0	100	0	90	0	0	0	0	0	0	0	0
NI	49	100	84	100	62	74	77	58	44	100	73	100
NB	0	100	90	96	4	12	44	26	0	0	80	100
N	0	100	90	90	0	0	0	0	0	0	0	0
O	0	100	88	90	0	0	0	0	0	0	0	0
P	23	100	90	100	48	50	0	20	43	99	0	100
PT	0	100	84	83	54	72	100	59	29	0	67	100
K	19	100	88	100	37	3	0	0	40	0	0	100
NG	72	100	89	100	30	0	44	77	33	100	83	40
RH	0	100	90	67	0	0	0	50	0	0	0	0
RU	0	100	84	67	0	0	0	0	0	0	0	0
OL	100	100	86	100	100	92	44	80	100	0	83	100
SE	0	100	75	67	1	19	34	67	0	0	83	100
SI	39	100	84	100	42	26	0	0	43	87	0	100
AG	0	100	77	96	36	78	100	86	57	0	67	100
NA	0	100	89	96	22	58	50	0	42	0	71	100
ST	0	100	83	100	0	0	0	64	0	0	0	0
S	47	100	88	67	44	45	57	68	40	100	73	99
TA	0	100	89	90	0	0	67	65	0	0	73	100
E	0	100	79	67	0	0	0	46	0	0	0	0
TL	0	100	70	67	0	0	0	72	0	0	0	0
SN	48	100	70	100	51	60	83	90	38	100	71	100
TI	0	100	87	96	36	56	34	63	25	0	100	100
W	33	100	83	90	28	34	44	76	21	0	77	99
V	0	100	87	90	0	20	0	37	0	0	0	98
XE	0	100	0	90	0	0	0	0	0	0	0	0
Y	0	100	8	83	0	0	0	41	0	0	0	0
ZN	56	100	81	96	52	39	81	40	53	77	72	95
ZI	6	100	84	83	4	0	44	67	5	0	77	100
CI	87	100	87	100	56	53	44	18	55	100	83	55
TH	0	100	100	83	0	0	100	20	0	0	67	100
U	0	100	100	83	0	0	100	55	0	0	67	0
RE	0	100	87	100	0	0	0	39	0	0	0	100

Notes : See Table 3.5

Table 3.7 - Sub Totals of Points Awarded to the Three Main Criteria Groups and the Total-Base Run

ELEMENT	ECONOMIC	QUANTITIES	AVAILABILITY	TOTAL
AL	270	385	218	873
SB	102	352	232	687
AR	0	189	0	189
AS	0	276	67	343
BA	9	282	77	369
BE	0	290	41	331
BI	16	272	207	495
B	39	288	62	389
BR	0	282	0	282
CD	56	356	72	483
CS	0	188	0	188
CA	110	329	127	566
C	0	100	0	100
CL	0	189	129	318
CR	98	276	171	546
CO	51	273	198	523
CU	307	369	232	908
FL	39	289	186	514
GA	0	180	0	180
GE	8	277	240	524
AU	219	283	267	769
HF	0	184	5	189
HE	0	187	0	187
H	0	198	0	193
IN	0	172	77	250
I	0	285	0	285
FE	321	352	209	882
KR	0	100	0	100
PB	170	373	242	785
LI	0	188	26	214
MG	150	380	184	714
MN	109	277	204	589
HG	22	280	251	554
MO	102	287	194	583
NE	0	100	0	100
NI	227	384	208	820
NB	17	290	150	457
N	0	190	0	190
O	0	188	0	188
P	164	390	20	574
PT	155	284	225	665
K	99	288	0	388
NG	135	328	204	667
RH	0	190	50	240
RU	0	184	0	184
OL	392	286	206	884
SE	20	275	184	479
SI	150	371	0	521
AG	166	277	253	696
NA	122	289	121	532
ST	0	183	64	247
S	176	387	199	762
TA	0	289	205	494
TE	0	179	46	225
TL	0	170	72	242
SN	196	370	244	811
TI	117	287	197	601
W	116	283	196	595
V	20	286	37	343
XE	0	100	0	100
Y	0	139	41	230
ZN	200	353	192	746
ZI	15	284	188	487
CI	251	342	144	737
TH	0	300	137	486
U	0	200	222	422

Notes : See Table 3.5

Table 3.8 - Final Ranking of Materials in Descending Order of Significance - Base Run.

POSITION	ELEMENT	POINTS	CRITERIA CONSIDERED	POINTS/CRITERION
1	CU	908	11	83
2	OL	884	11	80
3	FE	882	11	80
4	AL	873	11	79
5	NI	320	11	75
6	SN	811	11	74
7	PB	785	11	71
8	AU	769	9	85
9	S	762	11	69
10	ZN	746	11	68
11	Cl	737	11	67
12	MG	714	11	65
13	AG	696	9	77
14	SB	687	11	63
15	NG	667	11	61
16	PT	665	9	74
17	TI	601	10	60
18	W	595	11	54
19	MN	589	10	59
20	MO	583	10	58
21	P	574	10	57
22	CA	566	11	52
23	HG	554	9	62
24	CR	546	10	55
25	NA	532	9	59
26	GE	524	9	58
27	CO	523	10	52
28	SI	522	10	52
29	FL	514	9	57
30	BI	495	9	55
31	TA	494	9	55
32	ZI	487	10	49
33	TH	486	7	69
34	CD	483	10	48
35	SE	479	9	53
36	NB	457	10	46
37	U	422	5	84
38	B	389	8	49
39	K	388	9	43
40	BA	369	8	46
41	AS	343	8	43
42	V	343	9	38
43	BE	331	7	47
44	RE	326	7	47
45	CL	318	5	64
46	IO	285	8	36
47	BR	283	8	35
48	IN	250	3	83
49	ST	246	3	82
50	TL	242	3	31
51	RH	240	4	40
52	Y	230	2	115
53	TE	225	4	56
54	LI	214	3	71
55	H	198	4	50
56	N	190	4	48
57	AR	189	3	63
58	HF	189	2	95
59	O	188	4	47
60	CS	187	3	62
61	HE	187	3	62
62	RU	184	3	61
63	GA	180	3	60
64	XE	100	2	50
65	NE	100	3	33
66	KR	100	2	50
67	C	100	0	0

Notes : See Table 3.5

the industrially important materials are near the top of both rankings due to the availability of published data and consequent high points awarded.

Table 3.8 allows comparison of the changes necessary for individual materials to alter its positions in the table. For example, to equate iron with copper 26 extra points would be necessary which would arise for example from an SLI decrease from 233 years to 38 years.

In future tables, only the twenty top materials will be listed in order to provide a readily assimiable format.

3.11 Sensitivity Analysis

Implicit in the nature of the base run are the inbuilt unintentional prejudices of the assessor, and in order to assess whether these prejudices can significantly affect the end-result a sensitivity analysis was carried out.

Table 3.9 - Table of Weightings Applied for Sensitivity Analysis

Run No.	WEIGHTING FACTORS - SUB-TOTALS			Individual Criterion Weightings	COMMENT
	Economic	Quantities	Availability		
1	1	1	1	None	Base run
2	1	0	0	None	
3	0	1	0	None	
4	0	0	1	None	
5	2	1	1	None	
6	1	2	1	None	
7	1	1	2	None	
8	3	1	1	None	
9	1	3	1	None	
10	1	1	3	None	
11	1	1	1	BOP criterion x 2	
12	1	1	1	Ratio actual/ potential recycle x 2	
13	1	1	1	Cons. value x 2	
14	1	1	1	BOP, potential/actual recycle and cons. value x 2	Runs 11, 12,13, together

The first ten sensitivity runs concentrated on the sub-totals of points awarded for the three criteria groupings. Weighting factors were applied as shown in Table 3.9 and the results are presented in Table 3.10 for the top twenty materials in each run.

By analysing for each group of criteria, as in runs 2, 3 and 4 it can be seen from Table 3.10 that no single group has a dominating influence over the base case although some interesting results arise. For example, the quantities sub group is headed by phosphorus and sulphur closely followed by the major metals and carbon based organics. This is mostly because they are imported and processed in the UK to yield high value products from low value imports. It is possible that a more comprehensive interpretation of available data may enable the separation of production from UK reserves and the processing of imported material.

Runs 5 to 10 show the effect of allocating additional significance to each sub-group of criteria above that given in the base run. This is achieved by giving weighting factors of two and then three to each criteria sub-group in turn, with other sub-groups being allocated a weighting factor of one. No major differences to the base run can be observed although minor changes in position do occur. It is however worth noting that oil is sensitive to the economic criteria (cases 2,5 and 8), coal less so, and natural gas is quite insensitive.

In order to achieve the object of this chapter, i.e. to identify those materials where increased recycling effort would be beneficial to the U.K., four additional runs were carried out (runs 11-14) where the weighting factors were designed to reflect those materials where potential for a beneficial change in the Balance of Payments and consumption value would be possible through realising a potential for increased recycling activity. In fact the results of runs 11 to 14 do not differ significantly from

CASE 1 BASE CASE			CASE 2		CASE 3		CASE 4		CASF 5		CASE 6		CASE 7	
ORDER		POINTS		POINTS		- POINTS		POINTS		POINTS		POINTS		POINTS
1	CU	908	OL	392	P	390	AU	267	OL	1276	CU	1277	CU	1140
2	OL	884	FE	321	S	387	AG	253	CU	1215	AL	1259	FE	1092
3	FE	882	CU	307	AL	385	HG	251	FE	1203	FE	1235	AL	1091
4	AL	873	AL	270	NI	384	SN	244	AL	1143	NI	1204	OL	1091
5	NI	820	Cl	251	MG	380	PB	242	NI	1047	SN	1181	SN	1054
6	SN	811	NI	227	PB	373	GE	240	SN	1007	OL	1170	AU	1036
7	PB	785	AU	219	SI	371	CU	232	Cl	988	PB	1158	NI	1028
8	AU	769	ZN	200	SN	370	SB	232	AU	988	S	1148	PB	1026
9	S	762	SN	196	CU	369	PT	225	PB	954	ZN	1099	S	961
10	ZN	746	S	176	CD	356	U	222	ZN	947	MG	1095	AG	949
11	Cl	737	PB	170	ZN	353	AL	218	S	938	Cl	1079	ZN	938
12	MG	714	AG	166	SB	352	FE	209	MG	865	AU	1052	SB	918
13	AG	696	P	164	FE	352	NI	208	AG	862	SB	1039	MG	898
14	SB	687	PT	155	Cl	342	BI	207	PT	820	NG	995	PT	890
15	NG	667	MG	150	CA	329	OL	206	NG	802	AG	973	Cl	881
16	PT	665	SI	150	NG	328	TA	205	SB	789	P	963	NG	871
17	TI	601	NG	135	TH	300	MN	204	P	738	PT	949	HG	805
18	W	595	NA	122	NB	290	NG	204	TI	718	CA	896	TI	798
19	MN	589	TI	117	BE	290	S	199	W	712	SI	893	MN	793
20	MO	583	W	116	TA	289	CO	198	MN	698	TI	889	W	792

CASE 8			CASE 9		CASE 10		CASE 11		CASE 12		CASE 13		CASE 14	
ORDER		POINTS		POINTS		POINTS		POINTS		POINTS		POINTS		POINTS
1	OL	1667	CU	1646	CU	1372	OL	984	CU	982	CU	991	OL	1167
2	FE	1524	AL	1644	AL	1309	CU	979	OL	967	OL	984	CU	1136
3	CU	1522	NI	1588	AU	1302	FE	955	FE	951	FE	953	FE	1093
4	AL	1413	FE	1587	FE	1301	AL	936	AL	946	AL	947	AL	1083
5	NI	1274	SN	1551	SN	1298	NI	863	NI	892	NI	868	NI	984
6	Cl	1239	S	1535	OL	1297	SN	848	SN	881	SN	858	SN	967
7	AU	1207	PB	1531	PB	1268	AU	810	PB	852	PB	841	Cl	962
8	SN	1203	MG	1475	NI	1236	S	802	AU	836	Cl	824	ZN	927
9	ZN	1147	OL	1456	AG	1202	ZN	799	S	835	S	809	S	923
10	PB	1124	ZN	1453	S	1160	Cl	792	Cl	820	ZN	803	PB	909
11	S	1114	Cl	1420	SB	1150	PB	785	ZN	818	AU	769	AU	877
12	AG	1028	SB	1392	ZN	1131	AG	753	MG	785	MG	768	MG	866
13	MG	1015	P	1353	PT	1115	MG	741	AG	763	NG	739	NG	854
14	PT	974	AU	1336	MG	1082	SB	712	SB	756	SB	709	AG	819
15	NG	937	NG	1324	NG	1074	NG	700	NG	750	AG	696	SB	803
16	P	902	SI	1265	HG	1057	PT	694	PT	731	PT	665	PT	761
17	SB	891	AG	1251	Cl	1026	MN	630	TI	701	W	629	MN	733
18	TI	836	PT	1233	GE	1003	TI	626	W	672	MN	621	W	726
19	W	828	CA	1225	MN	997	P	617	MN	662	MO	607	TI	726
20	SI	823	CD	1195	TI	995	W	616	MO	659	CA	603	MO	716

Table 3.10 - Results of Sensitivity Analysis on Base Run

the base run although in run 11 (increased signficance of Balance of Payments Criterion) lead moved from sixth to eleventh position and in run 13 (increased significance of consumption value criterion) gold moved from eighth to eleventh position. In the final run (number 14) there were no major changes although oil replaced copper in the top position. Overall copper was in the top position for half the runs (seven out of fourteen) while oil was in the top position for five of the fourteen runs.

3.12 Additional Sensitivity Analysis

In section 3.11 an analysis by element identified copper as the material most worthy of further investigation. Oil was also identified as being of significance to the UK but any potential for increased recycling activity could only arise from the non-fuel uses of oil. In addition, the validity of the results for oil are in doubt because of the effect of North Sea Oil. These non-fuel uses are numerous and range from bitumen to chemical feedstocks and a great deal of work would be necessary before all these uses could be included in the assessment procedure. Instead, one material, lubricating oil, was selected for inclusion in the significance assessment procedure because of its potential for recycling and the large volumes involved.

Paper was also included as an example of a renewable resource which is a growing major component of domestic refuse which was also included as the largest non mineral potential source of secondary materials (Ref. Chapter 2).

Data on these three materials: lubricating oil, paper and domestic refuse were collected and included in the analysis. These criteria values are given in Table 3.11 below and the sub-totals and totals number of points obtained in Table 3.12. Finally, the points awarded are rearranged into descending order in Table 3.13. Domestic refuse scores low points in the

Table 3.11 - Criteria Values for Lubricating Oil, Paper and Domestic Refuse

Material	Consumption Value	UK Res	Growth Rate	By-co main	Imp Val	Exp Val	Act recycle	SLI	BOP (i)	Cons prod	Potential recycle ratio	Cons Imp
LO	244250(a)	1	26(b)	n.a	137(d)	75(d)	8	35(b)	-62	1	49	100
PA	2.67×10^6 (f)	1	30(e)	n.a	300(g)	20(g)	28	-2	-280	55(f)	25	48(f)
DR	360000(h)	1	10(c)	n.a	0	0	3	-2	0	100(h)	100	0(h)

Notes as Table 3.5 plus

(a) Pearce (173)
(b) As for petroleum
(c) UK not world growth rates
(d) Production Monitor (174)
(e) Turner (175)
(f) Thomas (58)
(g) Bridge (176)
(h) Domestic and industrial waste valued at £8/tonne (53)
(i) BOP = Balance of Payments

Table 3.12 - Sub totals of points awarded and total including paper, lubricating oil and domestic refuse.

ELEMENT	ECONOMICS	QUANTITIES	AVAILABILITY	TOTAL
AL	264	381	217	863
SB	100	353	242	695
DR	68	265	150	483
AS	0	252	77	329
BA	9	283	88	380
BE	0	285	0	285
BI	16	272	124	412
B	39	286	61	386
BR	0	288	0	288
CD	49	356	85	490
CS	0	200	35	235
CA	126	323	127	575
CL	0	189	129	318
CR	106	275	190	571
CO	51	282	211	544
CU	304	365	235	903
FL	39	287	200	526
GA	0	192	0	192
GE	8	277	254	539
AU	219	279	257	755
HF	0	100	0	100
HE	0	100	10	110
H	0	191	0	191
IN	0	178	0	178
I	0	282	23	305
FE	350	356	228	934
PA	313	362	162	837
PB	165	375	246	786
LI	0	190	0	190
MG	145	371	144	660
MN	103	275	192	570
HG	22	262	259	543
MO	96	287	205	588
NE	0	100	0	100
NI	227	379	226	832
NB	17	287	164	468
N	0	182	0	182
O	0	184	0	184
P	158	389	66	613
PT	155	281	239	675
K	93	283	52	428
NG	129	327	211	667
RH	0	179	55	234
RU	0	185	0	185
OL	386	279	215	880
SE	20	284	187	490
SI	153	371	0	524
AG	166	275	264	705
NA	122	291	121	533
ST	0	172	76	248
S	157	382	216	755
TA	0	288	218	506
TE	0	174	67	240
TL	0	100	97	197
SN	193	371	240	804
TI	117	287	195	599
W	110	279	206	594
V	20	285	54	359
LO	268	313	242	823
Y	0	100	0	100
ZN	198	348	247	793
ZI	19	281	199	499
Cl	254	255	161	669
TH	0	298	211	509
U	0	197	250	448
RE	0	284	60	344

Table 3.13 - Final Order of Materials in Descending Order of Importance including Paper, Lubricating Oil and Domestic Refuse

POSITION	ELEMENT	POINTS	CRITERIA	POINTS/CRITERIA
1	FE	934	11	85
2	CU	903	11	82
3	OL	880	11	80
4	AL	863	11	78
5	PA	837	11	76
6	NI	832	11	76
7	LO	823	11	75
8	SN	804	11	73
9	ZN	793	11	72
10	PB	786	11	71
11	S	755	11	69
12	AU	755	9	84
13	AG	705	9	78
14	SB	695	11	63
15	PT	675	9	75
16	Cl	669	11	61
17	NG	667	11	61
18	MG	660	11	60
19	P	613	10	61
20	TI	599	10	60
21	W	594	11	54
22	MO	588	10	59
23	CA	575	11	52
24	CR	571	10	57
25	MN	570	10	57
26	CO	544	10	54
27	HG	543	9	60
28	GE	539	9	60
29	NA	533	9	59
30	FL	526	9	58
31	SI	524	10	52
32	TH	509	7	73
33	TA	506	9	56
34	ZI	499	10	50
35	SE	490	9	54
36	CD	490	10	49
37	DR	483	11	44
38	NB	468	10	47
39	U	448	5	90
40	K	428	9	48
41	BI	412	9	46
42	B	386	8	48
43	BA	380	8	48
44	V	359	9	40
45	RE	344	7	49
46	AS	329	8	41
47	CL	318	5	64
48	I	305	8	38
49	BR	288	8	36
50	BE	285	7	41
51	ST	248	3	83
52	TE	240	4	60
53	CS	235	3	78
54	RH	234	4	58
55	TL	197	3	66
56	GA	192	3	64
57	H	191	4	48
58	LI	190	3	63
59	RU	185	3	62
60	O	184	4	46
61	N	182	4	45
62	IN	178	3	59
63	HE	110	3	37
64	Y	100	2	50
65	NE	100	3	33
66	HF	100	2	50

economics sub-total while paper has a relatively low score in the availability sub-total. Lubricating oil scores highly in all three sub-total groups. Looking at Table 3.13 it must be remembered that the scoring procedure depends upon a normalising procedure which makes comparison with the previous base run in Table 3.10 of limited use, but paper and lubricating oil are found in the high positions of five and seven respectively while domestic refuse is ranked thirty seventh in significance.

A sensitivity analysis using the weighting factors given in Table 3.9 was carried out and the results are presented in Table 3.14 with the exception of runs 8a, 9a and 10a which did not produce significant changes in the first part of the sensitivity analysis, and so were excluded from this analysis.

The insertion of paper, lubricating oil and domestic refuse into the list of materials under investigation does not significantly affect the results compared to the initial run although small changes can be observed. In run 1a, the new base run, paper is in fifth position while lubricating oil is in seventh position. In none of the sensitivity runs did domestic refuse appear in the top twenty lists while paper and lubricating oil did appear in lists with the exception of paper in run 4a (availability criteria only) explained by its low score of 162 in this sub-group. In addition paper and lubricating oil are generally in the upper half of the top twenty lists and in run 14a which is designed to identify, in particular, those materials where increased recycling effort would benefit the UK Balance of Payments, lubricating oil and paper are found in positions 5 and 6 respectively. It must be concluded that paper and lubricating oil show definite incentives for increased recycling activity.

Table 3.14 - Sensitivity Analysis Including Paper, Lubricating Oil and Domestic Refuse

1a	2a	3a	4a	5a	6a	7a	11a	12a	13a	14a
FE 934	OL 386	P 389	AG 264	FE 1285	FE 1290	FE 1163	FE 1034	FE 1010	FE 1002	FE 1178
CU 903	FE 350	S 382	HG 259	OL 1266	CU 1268	CU 1138	CU 1003	CU 998	CU 970	CU 1165
OL 880	PA 313	AL 381	AU 257	CU 1207	AL 1244	OL 1096	OL 980	OL 980	OL 963	OL 1163
AL 863	CU 304	NI 379	GE 254	PA 1150	NI 1211	AL 1080	AL 963	AL 960	AL 935	AL 1132
PA 837	LO 268	PB 375	U 250	AL 1127	PA 1199	LO 1065	PA 937	NI 932	PA 917	LO 1113
NI 832	AL 264	SI 371	ZN 247	LO 1091	SN 1175	NI 1058	NI 932	PA 926	LO 913	PA 1106
LO 823	Cl 254	SN 371	PB 246	NI 1059	PB 1161	SN 1043	LO 923	LO 923	NI 905	NI 1105
SN 804	NI 227	MG 371	LO 242	SN 996	OL 1159	ZN 1040	SN 904	SN 904	SN 874	SN 1074
ZN 793	AU 219	CU 365	SB 242	ZN 991	ZN 1141	PB 1032	ZN 893	ZN 888	ZN 865	ZN 1060
PB 796	ZN 198	PA 362	SN 240	AU 974	S 1138	AU 1012	PB 886	PB 884	PB 854	PB 1052
S 755	SN 193	FE 356	PT 239	PB 951	LO 1136	PA 999	S 855	AU 855	S 829	S 1028
AU 755	AG 166	CD 356	CU 235	Cl 922	SB 1048	S 972	AU 855	S 854	AU 822	AU 1022
AG 705	PB 165	SB 353	FE 228	S 912	AU 1034	AG 969	AG 805	AG 805	AG 792	AG 972
SB 695	P 158	ZN 348	NI 226	AG 871	MG 1031	SB 937	SB 795	SB 775	SB 764	SB 944
PT 675	S 157	NG 327	TA 218	PT 830	P 1002	PT 914	PT 775	PT 775	Cl 751	PT 942
Cl 669	PT 155	CA 323	AL 217	MG 805	NG 994	NG 878	Cl 769	MG 751	NG 750	MG 922
NG 667	SI 153	LO 313	S 216	NG 797	AG 980	Cl 829	NG 767	Cl 724	PT 742	Cl 906
MG 660	MG 145	TH 298	OL 215	SB 795	PT 956	MG 804	MG 760	P 713	MG 731	TI 899
P 613	NG 129	NA 291	CO 211	P 791	Cl 924	HG 802	P 713	NG 707	TI 699	NG 890
TI 599	CA 126	BR 288	NG 211	TI 716	CA 898	W 799	TI 699	TI 699	W 670	W 870

3.13 Summary and Conclusions

A methodology to identify the significance of materials using available data has been developed and a comprehensive examination of the signficance of materials to the UK has been carried out. An initial analysis identified copper, aluminium, iron and oil to be of particular importance and deserving of the greatest attention in their efficiency of utilisation. Iron, as the cornerstone of large scale industrial processes, has been investigated in great detail (see for example (81)). Copper, in contrast, has been investigated but only as to the methods and processes for economic recovery of scrap. Aluminium, as a "new" metal has been the subject of similar investigations which also included the use of a ready source of statistical information provided by the limited number of companies operating aluminium production/consumption plants. Copper was therefore selected for further examination in this project.

A further analysis which included paper and lubricating oil showed a surprising potential for increased recycling activity. Lubricating oil was selected as a major non-fuel use of oil, already identified as an important material while paper was included as a renewable resource which comprised a large proportion of domestic refuse.

In view of the above analysis it was decided to investigate copper to develop a methodology to investigate the potential and effects of increased recycling activities and the mechanisms by which this potential could be realised.

CHAPTER 4 THE STRUCTURE OF THE U.K. COPPER INDUSTRY

4.1 Introduction

Copper was identified in Chapter 3 as a material deserving further investigation into the effects of increased UK recycling activity.

Historically, the UK was a major producer and manufacturer of copper and copper based goods but now the UK copper industry is heavily dependent on imports of copper to manufacture goods for export, thereby affecting the Balance of Payments.

The importance of copper to the UK economy means that considerable information is available on various aspects of the industry but that the information is usually disorganised and often variously interpreted by representatives of interested parties. Even the terms used - resources, reserves, recycling - as shown in Chapter 2 are open to different interpretations. Yet the corporate planners who provide estimates of future activity levels and profitability of the copper industry, including the scrap sector, must be given a factual and analytical basis on which to develop their plans. Often such an analysis is not possible or is not carried out, for example, because of the complexity of the problem and this is discussed in Chapter 7. The object of the Chapters on copper is to develop a framework, based on a mass balance approach and the technical and economic factors affecting the mass balance, for analysing the respective industries and their problems. The possible effects of various measures can then be examined so that effective policy decisions, at a corporate planning level, can be made.

In this chapter, the flow of copper within the UK is described together with the structure and patterns of ownership of the UK copper industry. This is followed in Chapter 5 by an anlysis of available copper statistics for the period 1922-1976 and the trends in the major UK and World copper statistics. In Chapters 6 to 9 a qualitative and quantitative analysis of the factors affecting UK copper flows is made while in Chapter 10 the effect upon the mass-balance of the UK copper industry of various policy decisions is examined.

4.2 U.K. Copper Flows

4.2.1 Introduction

A diagram of copper flows in the UK developed from the generalised system described in Figure 2.10 is given in Figure 4.1. The flow conveniently starts with the production and trade of primary and secondary refined copper and alloy ingots which, together with the direct use of scrap, are the feedstock for the semi-manufacturers, who are the central unit or focus of the industry and who produce shapes such as wire, sheet or tube. The semi-manufactures are further processed into fabricated goods such as heat-exchangers or electrical cable and delivered to the final consumers. After a period of useful service, the fabricated goods are discarded and some scrap material is either collected by scrap merchants or fed directly to the scrap consumers. Copper scrap is used in one of three ways; it is either returned to the secondary refiners for the production of refined copper, used to produce alloy ingots or used directly by the semi-manufacturers.

In the following sections, the major steps involved in the copper flows described above will be discussed so that an assessment of the differences between the primary and secondary copper industries can be made and the existence of both in the UK explained.

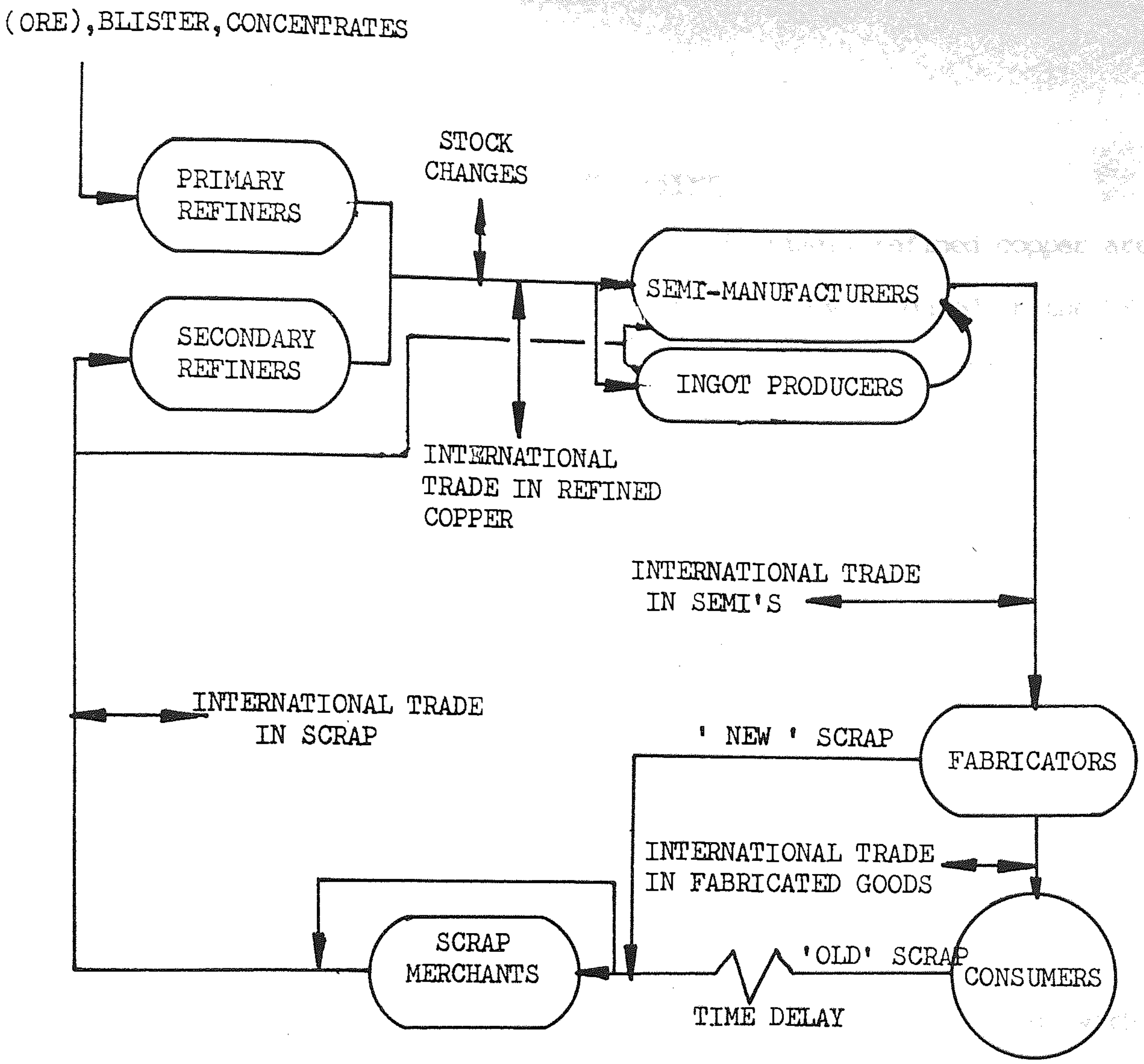


FIGURE 4.1 GENERALISED FLOW OF COPPER IN THE U.K.

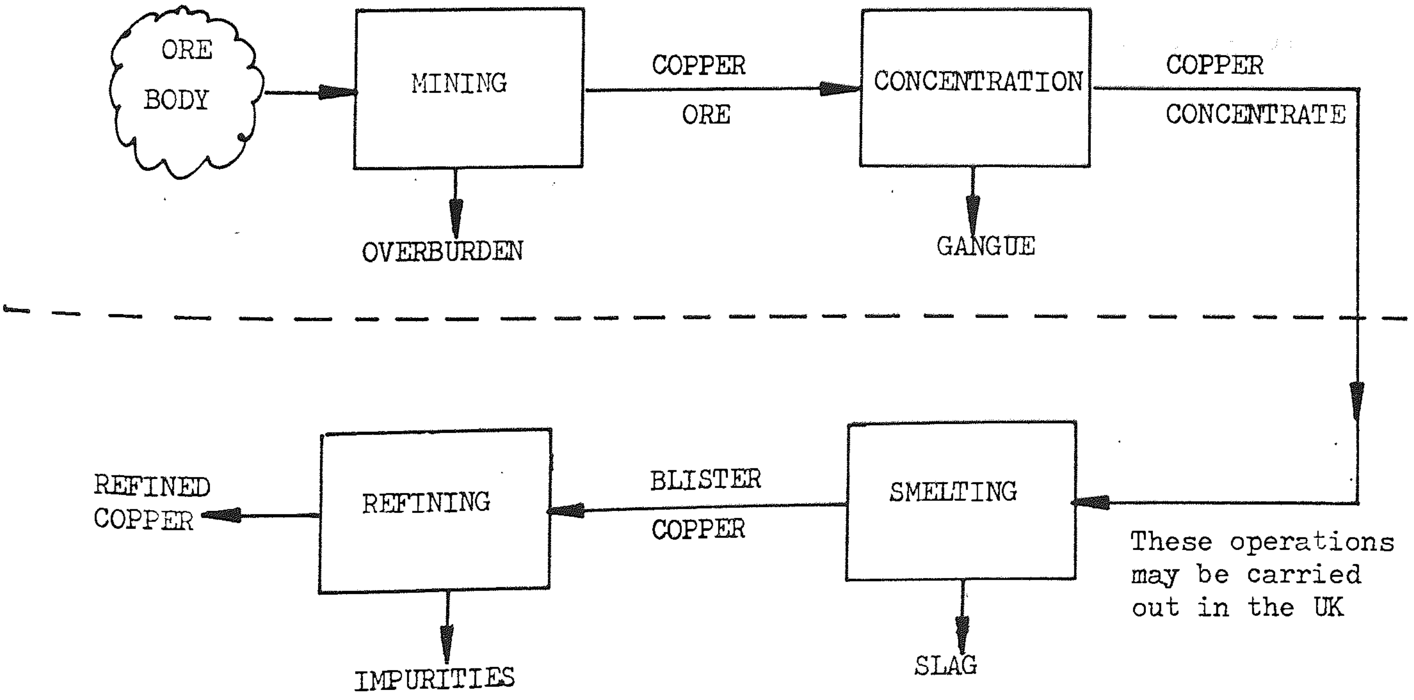


FIGURE 4.2 THE PRINCIPAL STEPS IN THE PRODUCTION OF PRIMARY REFINED COPPER

4.2.2 The Production of Primary Refined Copper

The principal stages in the production of primary refined copper are shown in Figure 4.2. Although no refined copper is now produced in the UK from indigenous ores some refined copper is produced from imports of concentrates, matte and blister copper. The steps involved are:

1) Mining and Concentration

Copper is estimated (82) to form 0.0055% of the Earths crust. The percentage of copper found in exploited ore varies with the size of the deposit and hence the scale of operation. Generally, the less common oxide ores are of a higher grade than the more common sulphide ores. For many years the average ore grade has been declining (83). During the period 1960 to 1970 the average grade fell from 1.5% to 1.25% and typical new major projects will exploit ore in the range 0.4% to 1% copper. This decline in ore-grade has led to the increased use of open-cast mining methods with associated investment in massive earth moving equipment.

With the large amounts of waste material or gangue present, copper ores are normally concentrated before smelting. Typically, about 90% of the copper present in the ore is recovered as concentrates averaging 25-30% copper content.

2) Smelting

During the smelting process, the concentrates are roasted to remove some of the impurities and then smelted with a limestone flux to form a slag and a copper matte containing about 40% copper associated with sulphur, base metals and precious metals. The matte is then transferred to a converter where the sulphur is removed as sulphur dioxide and the iron content forms a slag. The copper is then cast into cakes of blister copper containing 98-99.5% copper.

3) Refining

Remaining impurities in the blister copper, preventing its use in many applications and in particular electrical applications, are removed in the refining process. The refining process can either be fire-refining or electrolytic refining.

In fire-refining, the remaining sulphur is removed from the molten blister copper by further blowing with air and subsequent removal of dissolved oxygen by poling so preventing the formation of copper oxide during solidification. The fire-refined copper may then be cast into anodes and electro-refined to remove undesirable impurites and to separate valuable impurities, an important by-product of copper production. The cathodes of 99.99% copper produced are mechanically weak and are usually remelted and cast as wire bars although some cathodes are sold directly to alloy ingot manufacturers.

4.2.3 The Production of Secondary Refined Copper

The main features of a typical secondary refining operation are shown in Figure 4.3 (84). The steps involved are:

1) The Secondary Blast Furnace

The secondary blast furnace is fed by copper bearing scrap averaging 20% copper but which may contain non-metallic copper bearing materials such as copper oxides and hydroxides. Black copper containing 75% copper is produced.

2) Converting

The black copper is further processed by converting with higher grade scrap to produce blister copper for anode production. The copper and iron containing slag is fed back to the blast-furnace. Some black copper is

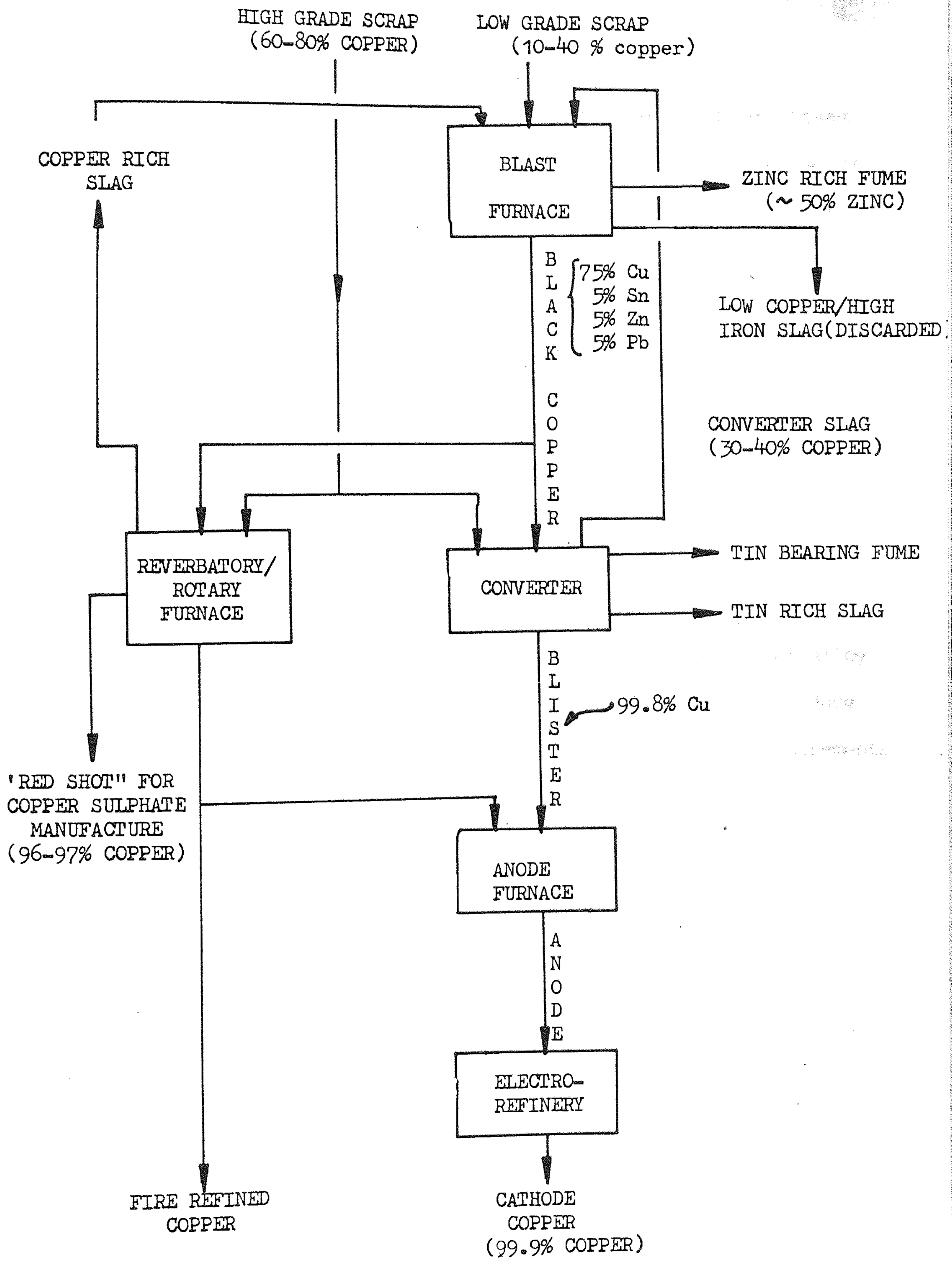


FIGURE 4.3 - PRODUCTION OF SECONDARY REFINED COPPER. (84)

processed in reverbatory or rotary furnaces with higher grade scrap to produce fire refined copper or for casting into anodes or the production of copper sulphate.

3) The Anode Furnace

The blister copper from the converters and partially refined copper from the reverbatory and rotary furnaces are fed to the anode furnace where the metal is deoxidised prior to casting into anodes in a similar fashion to the primary copper industry.

4) Electrolytic Refining

Electrolytic refining of secondary anodes produces copper cathodes equal in composition to primary refined copper. The impurities produced from secondary anodes are richer in lead and tin and leaner in nickel and precious metals than those found in the primary process.

4.2.4 Alloy Ingot Production

The alloy ingot makers clean, sort and grade copper and copper alloy scrap before melting and sometimes partially refining the scrap to produce specification ingots to British Standard or individual customers requirements. "Refining by dilution" by the addition of expensive refined copper is employed only when essential.

4.2.5 Copper Sulphate Production

All UK copper sulphate production is believed to be from secondary sources (84) using approximately 5000 tonnes/year of copper in copper scrap. The major steps in copper sulphate production are shown in Figure 4.4. Basically black copper from the secondary blast furnaces is further refined in a reverbatory furnace and then poured into water, producing red shot which is then dissolved in sulphuric acid to produce hot, saturate copper sulphate liquor. Crystallisation produces copper sulphate crystals containing 25% copper which is sold with a guaranteed minimum purity of 98% copper sulphate.

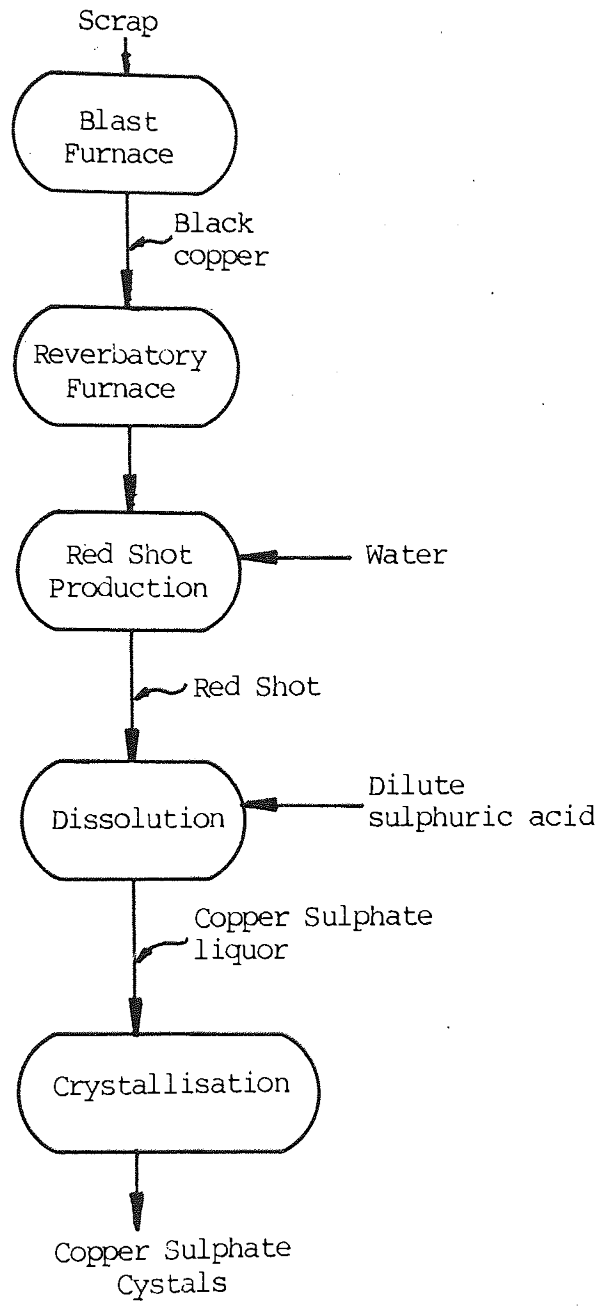


Figure 4.4 - Production of Copper Sulphate (84)

4.2.6 Semi-Manufacture Production

The semi-manufacturers are the central unit in the copper industry who convert unwrought refined copper, copper and copper alloy scrap and alloy ingots into wrought shapes for further processing by the fabricators. Figure 4.5 shows a breakdown of the UK production of semi-manufacturers for 1976 where it can be seen that unalloyed wire is the principal semi-manufacture. For this reason, rolling is the larger scale semi-manufacturing process producing unalloyed and alloyed wire, sheet, strip and plate. Rod, bar and sections, together with tube are produced by extrusion while the oldest process, castings produce intricate shapes by methods ranging from unsophisticated sand castings to die-castings.

The strict quality levels required for unalloyed wire production for electrical applications means that little scrap, other than home scrap or scrap which has been secondary refined, is used in this shape-group. Scrap may be used in the manufacture of all other shape groups.

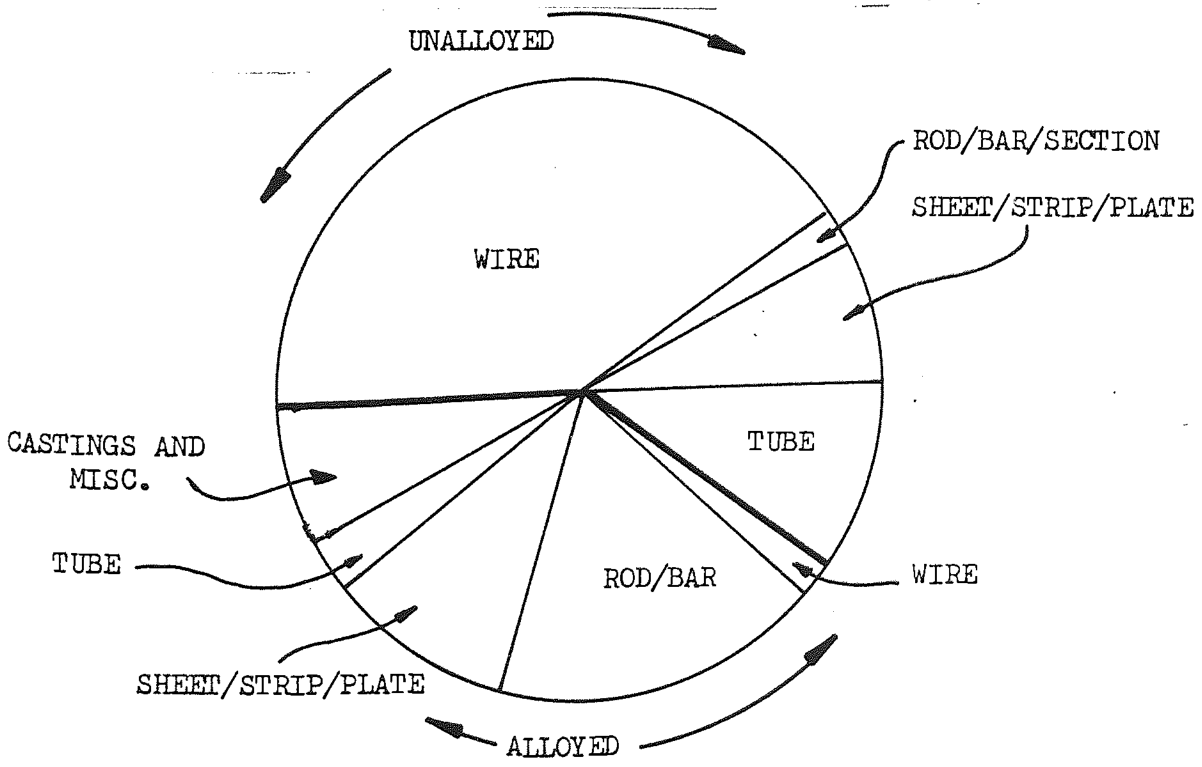


Figure 4.5 - Breakdown of U.K. Production of Semi-Manufactures, 1976, (gross) (85)

4.2.7 Fabrication

Reference to Figure 4.1 shows that the copper and copper alloy shapes produced by the semi-manufacturers are delivered to the fabricators where, together with other material inputs, they are used to produce a wide range of finished articles. Various attempts have been made to classify these end-uses, and these are discussed in more detail in section 4.3. Considerable variations occur between the different sources and Table 4.1 gives an approximate breakdown for the UK.

Table 4.1 - Major End-Uses of Copper in the U.K.
(Source : Table 4.5)

End-use	% of consumption	Description
Domestic Appliances	3	Cutlery, ornaments
Transport	12	Radiators, piping
General Engineering	15	Valves, bearings
Elecrical	52	Cable, wire
Construction	19	Plumbing, valves

During the fabrication process, as shown in Figure 4.1, large quantities of new scrap are generated which is either recycled to the secondary copper refiner or semi-manufacturer in the case of a vertically integrated operation or sold to a scrap merchant.

4.2.8 Scrap Metal Merchants

Scrap metal merchants handle a significant proportion of recycled copper and copper alloy scrap and in particular old scrap from copper consumers.

The scrap metal merchant receives a mixture of copper bearing scrap and other scrap from a variety of sources and sorts the scrap into component materials which are then sold to scrap consumers. In the case of copper the scrap metal merchants sell to either the secondary copper refiners, the ingot makers or the semi-manufacturers. In certain circumstances the scrap metal merchants will stock scrap until a more advantageous time. The mechanisms which motivate the scrap metal merchant to buy, sell and stock copper scrap and their effect upon the copper recycling industry will be discussed in Chapter 9.

There is a hierarchy in the scrap metal merchant industry, but not a rigid one. Refiners and scrap users only normally handle large loads of copper scrap which are supplied by the larger scrap merchants who, in turn, buy from progressively smaller merchants. The existence of a hierarchy and the desire to cut costs and to by-pass the next tier means that, contrary to normal business practice, the scrap merchant will pay a higher rate for larger loads of scrap than for small loads.

Tightening environmental legislation continues to affect the scrap merchants operations and this, combined with the increasing use of goods associating copper with other materials, notably PVC and other plastic insulation on cable and lead on copper tube, had led to increasing pollution control costs, a trend which is expected to continue. This trend and its effects will be discussed in a later section.

4.2.9 Copper Scrap Grades

For mass balance purposes, the various types of copper scrap described by source and destination have already been discussed, but the copper industry concerns itself with the copper content and contaminant levels of scrap and an alternative, more widely used system has been developed by industry to classify copper scrap along these lines.

There are several scrap classification codes available depending upon the country in question. In the UK system there are approximately 35 grades ranging from very high quality number one copper wire through copper cuttings to brass rod ends and low grade braziery. A full description of the scrap grades is irrelevant to the mass balance approach of this work and reference should be made to trade literature for a more detailed list. (For example, reference should be made to (86,87) or relevant trade associations).

In practice it is difficult to distinguish between scrap by source. Much old scrap may include some fabricated and semi-manufactured scrap. For example, it is difficult to distinguish between cable scrap which arises as either cable making scrap, cable scrap from firms installing plant and equipment and old cable scrap. New scrap is carefully segregated by the producing plant and is therefore of a known composition and in most cases can be used directly by the semi-manufacturers. Some new scrap produced by the fabricators, such as leaded brasses, will always be sold to refiners because they cannot be used directly by the semi-manufacturers.

In the course of manufacture, there is a downgrading of scrap. The new scrap produced by the fabricators of unalloyed copper is used in the main for brasses and much scrap can be used to produce bronzes but beyond this scrap is only fit for recycling.

Old scrap is used directly by ingot makers to a much larger extent than by semi-manufacturers, mainly because it is frequently contaminated by iron and tin and so it can only be used for specification ingot production. A larger proportion of old scrap however, is so contaminated that refining is the only option for recycling.

4.2.10 Major Differences Between the Primary and Secondary Copper Industries

Table 4.2 shows the main differences between a primary and secondary refining operation and the direct use of scrap. Although UK primary copper refiners use a very small amount of imported ores and concentrates, a large amount of imported blister and no indigenous ores, Table 4.2, in order to provide a true comparison, considers primary refined production from copper ore.

Table 4.2 shows that both primary refined production and the direct use of scrap operate with closely controlled limits on most of the parameters consideed. Secondary refining operations, on the other hand, have been developed to maintain a flexibility not found in the primary refining industry to cope with the wide physical and chemical range of feedstocks.

Table 4.2 - Main Differences Between Primary and Secondary Copper Refining and the Direct Use of Scrap

	Primary Refining	Secondary Refining	Direct Use of Scrap
1. Copper Content of Feed	Variable within small and predictable limits.	Very variable from ashes to car radiators.	Variable within specified limits.
2. Impurities in Feed	Variable within small limits. Few non-inert impurities.	Wide range. Non predictable. Non-inerts present.	Variable within specified limits.
3. Typical delivery loads	Continuous and very large.	Intermittent with possibly many small loads.	Intermittent but of reasonable size.
4. Physical Composition of Feed	Variable within small range i.e. ore particle size.	Extremely variable i.e. car radiators to ashes.	Within limits set by processing equipment.
5. Chemical Composition of Feed	Variable within narrow limits.	Extremely variable.	Tightly controlled.
6. Recovery route	Designed to suit constant grade of material.	Must have flexibility to suit feedstock.	Material must be compatable with primary input.
7. Pollution	Pollutants of constant composition	Pollutants variable and more noxious than from primary process e.g. PVC, lead.	Minimal pollution, assuming good sorting before remelting.

4.3 End-Uses of Copper and Copper Alloy Products

There are two main methods of examining the end-use pattern of copper consumption; firstly, consumption by semi manufacture type and secondly by final product. Consumption by semi-manufacture type has already been analysed (Section 4.2.6) with unalloyed wire being the major semi consumed followed by alloyed rod, bar and sections. Together these semis account for approximately 60% of total consumption.

The pattern of end-use by final product is difficult to establish but provides useful information on factors likely to affect copper demand. Statistical information on end-use patterns is scarce and that which is available is the product of one-off surveys and lacks uniformity in classification. This is because the inter-industry flows involved are complex and require detailed analysis before accurate reliable results can be obtained. Although such an analysis is possible using input-output tables for the UK, it is beyond the scope of this project. Instead, reference has been made to published estimates which generally break end-uses down into five main sections : electrical; construction; general engineering; transport and domestic appliances. Table 4.3 presents estimates by various sources for these end-uses of copper. Data availability problems means that reference has been made to surveys carried out in other countries. The final analysis presented in this section will show that consumption patterns in the UK, US and Western Europe are similar and so may be incorporated into the UK analysis providing that care is taken in data extraction.

Table 4.3 - Various Estimates of the Breakdown of End-Uses of Copper

(% of copper consumption)

Source, year and country	Electrical	Construction	General Engineering	Transport	Domestic Appliances	Other
CIDEC (88) 1965 UK	51	19	12	11	3	4
CIDEC (89) 1967 UK	65	-	16	14	5	-
WEST (90) 1966 UK	45	15	15	-	-	25
CDA (83) 1966 US**	26	23	17	13	21	-
CDA (83) 1967 US**	27	21	16	11	25	-
CDA (83) 1968 US**	26	21	16	13	24	-
SMITH (91) 1968 W. Europe	50	14	16	10	-	10
CDA (83) 1969 US**	27	21	16	12	24	-
GORDON (92) 1969 US	52*	19	17	12	*	-
CDA (83) 1970 US**	29	22	17	11	21	-
CHAPMAN (33) 1974 UK	41	12	11	4	2	30
GLUSCHKE (93) 1974 US	46	16	19	10	9	-
DAVIES (94) 1975 UK**	20	15	14	24		27
GLUSCHKE (93) 1975 Japan	52	9	15	17	7	-
GLUSCHKE (93) 1975 W. Europe	54	16	11	14	5	-
CDA (95) 1978 W. Europe	44	16	14	11	15	-

* Domestic applications included under electrical
**Assumed to take into account tertiary uses.

Table 4.3 shows that the major end-use of copper is for electrical applications accounting for approximately 50 percent of total consumption with the remainder being divided fairly equally between construction, general engineering and transport. Domestic applications appear to account for only a small proportion of the market.

The effects of so called tertiary wiring (i.e. the consumption of electrical goods in other sectors, such as copper wire in motors in automobiles) are significant. Gluschke (83) gives a revision of the breakdown of end-uses in Table 4.4 to include the effects of this tertiary wiring in the US.

Table 4.4 - The Effects of Tertiary Wiring Upon the End-Uses of Copper (USA) (83)

End-use	Not including tertiary wiring	Including tertiary wiring (approximate)
Electrical	46	31
Construction	16	19
General Engineering	19	19
Transport	10	12
Domestic Applications	9	16

The effect of including tertiary wiring is to decrease the significance of electrical uses by approximately 30 percent by reallocating consumption to construction, transport and in particular domestic applications. General engineering is not so affected.

The apparent inconsistencies between UK and USA consumption patterns in Table 4.3 can be explained by this phenomenom, with those estimates marked with the symbol (**) being assumed to take into account tertiary wiring. This rationalises the variations in the table and enables an average breakdown relevant to the UK to be estimated in Table 4.5.

This estimate does not include tertiary wiring as no comparison similar to Table 4.4 has been found for the UK, although signficant differences are unlikely.

Table 4.5 - Assumed Breakdown of UK Copper Consumption by End-Use

End-Use	Percentage of Consumption
Electrical	52
Construction	18
General Engineering	15
Transport	12
Domestic Appliances	3

Additionally, the estimates in Table 4.5 are the result of a subjective analysis of each classification in Table 4.3 and allows for such factors as unusually high unidentifiable uses. A major assumption in such as analysis is the lack of consideration given to changes in end-uses over time due to technological and consumer changes. No particular trend in any end-use sector can be observed and while possible if a detailed analysis of the Census of Production and other available statistics were to be made this is currently beyond the scope of this project.

4.3.1 Electrical Uses

The term "electrical industry" is used here to cover the generation, transmission, distribution and utilisation of electricity and includes some tertiary uses i.e. use of electrical components in cars, ships and building. Copper, with the highest electrical conductivity of any of the common metals has been the accepted material for conducting electricity since its commercial development. The electrical industry is therefore the major consumer of copper, accounting for 52% of total consumption. Table 4.6 shows that insulated wire and cable accounts for over half of total consumption with telecommunications accounting for another 20%.

Table 4.6 - Approximate Breakdown of Copper Consumption in the Electrical Industry (Western Europe) (91, 93)

Use	Percentage of Consumption	
a) Insulated wire and cable		
1) Transmission and distn. cables underground.	25	55
2) Wiring cables	30	
b) Transformers	7	
c) Motors and generators	8	
d) Switchgear	8	
e) Wiring Accessories	3	
f) Telecommunications		
1) Cable	16	19
2) Equipment	3	
TOTAL	100	

a) Wire and cable are an important use of copper and include cable for the transmission and distribution of electricity and cable used for example on house and factory installations, car wiring harnesses, ship wiring, flexible and trailing cables. Copper has been used almost exclusively in these applications although aluminium is being gradually introduced (see Chapter 7). High voltage cables used in electricity generation and distribution may be insulated with paper, lead, or plastic and are usually armoured. These are used primarily by the CEGB and Area Boards (for distribution) although some is used in factories, power stations, coal mines and railway electrification. A survey of the end-uses of copper in 1967 (89) concluded that a major factor in reduced copper demand around this time was the near completion of the British Rail electrification programme and a change away from bare strand overhead crane conductors and trolley wire. Wiring cables include all cables for wiring industrial, commercial and domestic buildings (40% of wiring cable consumption), ship and car wiring harnesses and domestic flexible cords. Growth in the building industry is the major factor affecting demand for wiring cables although ship and car construction also contribute.

b) Transformers use winding wire or magnet wires. Large power transformers involve complicated wiring procedures and economics calls for the minimum size of conductor which currently, in practical terms, means copper. Increases in the cost of copper has meant that the amount of copper per transformer has been reduced by technical innovation.

c) In many electric motors and generators, minimum conductor size is also vital so that copper is still in general use although economics in the use of copper has been introduced where possible (91).

d) Switchgear is responsible for a substantial use of copper but is such a diverse field that it cannot be detailed here. Consumption is mainly in the form of high conductivity strip, rod, extruded and drawn sections and castings. As the major volume user of switchgear is the CEGB and Area Boards any programme of increase in generating capacity will affect demand.

e) Wiring accessories include lamp caps, control panels, welding electrodes and contacts and are a small proportion of total electrical uses.

f) Telecommunications is still a relatively new expanding industry with 80% of the copper consumed in 1968 (91) going into multi-pair telephone cables used in built up areas. Copper consumption in telecommunication equipment accounts for only 3% of total consumption in Table 4.6, mainly in the form of nickel silvers, brass and bronze used in switches, relays, contacts, plugs and sockets in telephone exchanges.

Substitution for copper by other materials and in particular aluminium has been occurring over the past fifty years. The electrical industry is coppers single most important market and although aluminium only has 62% of the conductivity of copper, per unit volume it is one third its weight so that in order to reach the same conductivity it needs to be more bulky (83). Overhead power transmission lines were one of the first copper markets to be penetrated by aluminium as the weight reduction achieved allowed important reductions in the size of cable carrying structures and posts. Today few overhead lines are made from copper (93,96). The size of aluminium cables in comparison to copper limits aluminiums use in underground high tension cables, although the much larger low tension cable system is open to attack (93). In large power transformers, complicated winding procedures, plus the need to economise on expensive magnet steels calls for the minimum size of conductor i.e. copper. A similar argument may be applied to large electric motors and generators although, as the discussion in the transport industry section will show, small motors are changing to aluminium. The question of whether aluminium will substitute copper in building cable is open to much speculation. There are certain practical difficulties in making connections with aluminium rather than copper as aluminiums high creep leads to slack in these connections promoting oxidisation which, unlike copper, causes a rise in temperature and a subsequent fire risk. Copper clad aluminium wire may provide a solution but manufacturing costs are high. In switchgear uses, printed circuits and solid state relays are slowly having an effect.

For telecommunication cable, coppers vulnerability to substitution varies by type of cable. One estimate (91) put the secondary local network at 70% copper and 30% aluminium rising to maximum of 85% for old exchanges which have junctions requiring copper connectors. The primary local network is also gradually switching to aluminium with current orders averaging 33% aluminium, 66% copper. In the long term, copper (and aluminium) will face competition from alternative transmission systems such as wave guides and fibre optics.

4.3.2 Construction Uses

Copper is used in the construction industry either for electrical (Section 4.3.1) or non-electrical applications. Non-electrical uses of copper in the construction industry are given in Table 4.7 for Western Europe although similar breakdowns exist for West Germany (93).

Table 4.7 - Non-Electrical Uses of Copper in the Construction Industry (Western Europe) (91)

Use	% of consumption
Tubing	39
Plumbers fittings	34
Water heating systems	13
Builders hardware	9
Architectural uses	5
Total	100

In the UK, the use of copper for architectural purposes is not as extensive as in some continental countries and so the figure of 5% quoted above may be lower in the UK.

Copper has traditionally been used for hot water systems and in about 90% of all cold water lines (91) gradually replacing lead pipes. In the last twenty years the number of central heating systems installed has risen so affecting demand for copper. Gas lines in the UK are normally made from copper for both household supplies and for underground lines from the street main.

The end uses described utilise copper in three forms - tubing, plate and fittings. By far the most important of the three is copper tubing which may account for 70% of total consumption by the construction industry, compared to 15% each for plate and fittings (97).

It is unlikely that nylon and similar minibore heating systems will have a significant impact although in large buildings plastic is being used for trunk lines. In plumbing tubes the major threat is to cold water systems and guttering when PVC has become widely accepted. Plumbers fittings have held up well although pressure die casting means that copper usage in weight per unit has been reduced.

4.3.3 General Engineering Uses

General engineering includes the wide and diverse fields of mechanical engineering, machine tools, heat exchangers and other heavy industrial plant. An approximate breakdown for W. Europe is presented in Table 4.8.

Table 4.8 - Approximate Breakdown of Copper Use in the General Engineering Sector (W. Europe) (91)

Use	% of copper consumption
Heat Exchangers	17
Valves	20
Pumps	8
Refridgeration	6
Bearings	7
Other	42
Total	100

Engineering valves made mainly from gunmetal castings account for 20% of consumption in this sector, closely followed by heat exchangers where coppers use in the form of tube, particularly for power stations, desalination and chemical plant, is large. As a specific example, a 600 MW turbo alternator in a power station contains about 200 tonnes of copper alloy tubes and about 60 tonnes of tube plates (91).

Valves, pumps and fittings are large copper alloy users which have held their own in the face of competition from aluminium and stainless steel although the latter has made some inroads. Generally, coppers uses in this end-use are sufficiently diverse to make it safe from large scale substitution although light construction heat exchangers are open to some substitution. In refrigeration aluminium alloys are having an impact, particularly for cryogenic applications. Steel and titanium are being increasingly used in condensers for power stations and copper consumption per Megawatt of generating capacity is decreasing.

4.3.4 Transport Uses

The transport sector accounts for 12% of UK copper consumption and may be broken down into component industries as shown in Table 4.9.

Table 4.9 - Approximate Breakdown of Copper Consumption in the UK Transport Sector (Western Europe) (89,91)

Use	% of consumption
Road Vehicles	67
Ships	24
Railways	8
Aircraft	1

The use of copper in the aircraft industry is small with the copper content of a modern civil jet aircraft being about 2½% of total weight.

In rail transport, the major use of copper is in the motors and generators of diesel-electric and electric locomotives, overhead contact wire and in signalling and communication systems. Some substitution for copper in locomotive radiators may occur.

Shipbuilding accounts for 24% of copper consumption (91) with the most important uses of copper and its alloys being in propellors, feedwater heaters, electrical services and steam condensers on turbine driven ships. Generally, larger vessels have a lower copper content per tonne of vessel weight.

From the copper industries view, the car industry is by far the most important section of the transport industry group using 70% of total group copper consumption. A typical US automobile contains 0.9-1.0% copper (50) or for Western European cars between 9.5 and 11 kg per car broken down as follows: heater 1.5 kg (89,91), radiator 3.5 kg (91,97), starter motors 0.7 kg (91), dynamo 1.0 kg (91), wiring harnesses 1.0 kg (91), other (carburettor, bearings, selector forks, fuel pumps etc.) 2.3 kg (91). The substitution for copper in cars is unlikely to occur in vehicle wiring where the bulkiness of aluminium is a disadvantage, although aluminium windings in dynamos and starter motors are possible. The major area of substitution is the car radiator and heater where thinning of fins has been carried out over a number of years. There is some reluctance to move away from copper due to the capital invested in necessary production machinery. It is now estimated (97) that 20% of European cars have switched to alternatives including aluminium, plastics and steels. In the UK, Marston Radiators (97) have developed a miniature copper radiator using 25% less copper at 15% less cost. It would appear however, that substitute material radiators will only be considered when drastic design changes are envisaged.

4.3.5 Domestic Uses

There are a considerable number of familiar everyday goods which contain copper. Some of the more important are televisions, any item containing an electric motor, coinage, cutlery and pans. It has been argued (75) that in developed countries the domestic applications market for copper is saturated and little growth or decline will occur.

4.3.6 Summary of the End-Uses of Copper

It is clear from the analysis of the end-uses of copper presented that the major copper users are the electricity sector (including distribution and telecommunications) especially if tertiary wiring, in construction, transport etc., is included. These sectors are also those in which copper has, and will continue to be substituted for by other materials.

4.4 The Structure of the U.K. Copper Industry

4.4.1 Introduction

With no currently economic indigenous ore reserves, the U.K. copper industry relies entirely upon imports of primary refined copper. However, in the 18th and to a lesser extent 19th centuries, Great Britain was the major primary copper producer in the World. As a result of the decline of the U.K. copper mining industry, the U.K. copper industry now imports refined copper, supplements it with secondary material and exports a large proportion of its production as fabricated goods. The structure of the U.K. copper industry reflects this emphasis on the semi-manufacturing and fabrication industries and, in addition, the secondary copper collection and processing industries.

In this section, the various sectors of the U.K. copper industry are described to illustrate this structure. Additionally, the U.K. copper market structure is examined to determine the size of the firms involved and the extent of vertical integration.

4.4.2 Primary Refiners

Referring to section 4.2.2. the production of indigenous virgin refined copper in the U.K. is negligible although some refining of imported blister and matte copper takes place at secondary refiners. This blister originates mainly from Chile and Germany (85) and includes an unspecified quantity of electrodes for electrolytic refining. The majority of U.K. virgin refined copper originates from imports of metal.

4.4.3 Secondary Refiners

There are five major secondary refiners operating in the U.K. with a total capacity, including primary refining of 280,000 tonnes as shown in Table 4.10.

Table 4.10 - U.K. Secondary Refiners (1974) (98)

Company	Location	Capacity (tonnes)	Parent Company
British Copper Refiners	Prescot Widnes	45000 (e) 130000 (f) 175000	BICC
IMI Refiners	Walsall	45000 (e) 20000 (f) 65000	IMI
Elkington Copper Refiners	Walsall	27000 (e)	Brandeis Goldschmidt
McKechnie Bros	Widnes	9000 +5000 Cu in $CuSO_4$	McKechnie Bros.
Capper Pass	N. Ferriby	4000 (e)	RTZ
	TOTAL	280000	

Notes (e) = electrorefined (f) - fire refined production.

Due to the unavailability of data on capacity expansion and reduction it is difficult to comment upon the utilisation of this capacity, however, if U.K. secondary refining capacity is assumed to be constant at 280,000 tonnes (Table 4.10) then the maximum utilisation was 85% in 1961, although more recent calculations suggest about 70%.

Geographically, the secondary refiners are located near the major copper consumers, i.e. near the semi-manufacturers in the North West and Midlands as shown in Figure 4.6 and these locations reflect the historical

PRIMARY AND SECONDARY REFINERS

INGOT MAKERS

FIGURE 4.6 - GEOGRAPHICAL LOCATION OF THE U.K. COPPER INDUSTRIES

patterns of copper production and consumption in the U.K. Surprisingly, there is not a major secondary refiner in the London area although some sources do indicate that the Delta group of companies did have a 66,000 tonne capacity plant located at Brimodown (Enfield Metal Refining Co.).

4.4.4 Ingot Manufacture and Sulphate Production

The major ingot manufactures are shown in Table 4.11 and their geographical locations in Figure 4.6. As with secondary refining, ingot manufacture is dominated by BICC (30,000 tonnes) and IMI (87,000 tonnes), although other companies do have sizeable capacities. The ingot producers are much more disaggregated than the refiners with at least 27 companies with a unit capacity of less than 10,000 tonnes. This results from the nature of the operations of the ingot makers who can set up business with a simple small melting furance and carefully select and sort scrap for blending. Geographically, the ingot makers are located principally in the West Midlands where they are close to both the major sources of scrap and their customers. Pulling and Garner (99) estimate that 50% of ingot manufacture in the U.K. is from two companies; A.H. Cohen (IMI) and Tyseley Metals Ltd. (S.W. Wood) and although these figures differ from those given in Table 4.11 they may have more recent information. Only one major producer of copper sulphate operates in the U.K.; McKechnie Chemicals of Widnes who produce copper sulphate in addition to their secondary refining operations.

Table 4.11 - Major Ingot Manufacturers

Parent Co.	Co.	Location	Capacity (tonnes)
BICC	British Copper Refiners	Prescot	-
	Brookside Metal	Willenhall	30,000
	Telcon Metals	Crawley	-
			30,000
IMI	Wolverhampton Metal	Wednesfield	20,000
	A.H. Cohen	London/Glasgow	51,000
	R.M. Easdale	Glasgow	16,000
S.W. WOOD	Tyseley Metals	Birmingham	14,000
	John Allen (Glenpark)	Glasgow	12,000
ENGELHARD	Sheffield Smelting Co.	Sheffield	11,000
	Metal Product Ltd.	Wolverhampton	11,000
MCKECHNIE	McKechnie Chemicals	Widnes	5,000 $CuSO_4$
	Others		26,000
	TOTAL		191,000 +5,000 $CuSO_4$

4.4.5 Semi-Manufacturers

The semi-manufacturers are located principally in Manchester, Birmingham and London (as shown in Figure 4.6 and Table 4.12 for producing 10,000 tonnes/annum of copper goods) and are dominated by three companies: Delta (total capacity = 223,500 tonnes), BICC (195,000 tonnes) and IMI (180,000 tonnes) although about 60 other companies are listed in Copper 1974 (98) with capacities ranging from below a hundred to several thousand tonnes. A detailed business analysis of all the companies and products involved would be difficult and beyond the scope of this project. The reasons for this are two fold - firstly, the size of the industry causes many difficulties and secondly, both lateral and vertical integration has (and still is) taking place causing continual changes in the structure of the companies involved.

BICC, IMI and Delta are important at the national economy level; taking The Times list of 1000 top companies (110), ranked by turnover in 1977, BICC was number 34, Delta was 93 and IMI 94. As exporters they do well; they rank 16, 58 and 47 respectively, and in terms of numbers of employees, they rank 30, 55 and 74.

Table 4.12 - U.K. Semi-Manufacturers with 10,000 tonnes/annum Capacity (98)

Parent Co.	Company	Location	Capacity
BICC	Thos. Bolton	Prescot, Stoke	40,000
	Connollys (Blackly) Wire Div.	Blackly	15,000
	BICC	Prescot, Leigh	140,000
		TOTAL	195,000
DELTA	Delta Metal	W. Bromwich	60,000
	Borker and Allen	Birmingham	5,000
	Delta Tubes	Birmingham	30,000
	Enfield Rolling Mills	Brimsdown	100,000
	Enfield Winding Wires	Brimsdown	3,500
	ERM Rolled Metals	Brimsdown	25,000
		TOTAL	223,500
IMI	IMI (Kynoch) Rod/Wire	Birmingham	30,000
	" Rolled Metals	Birmingham	70,000
	Yorkshire Imperial	Smethwick, Leeds	80,000
		TOTAL	180,000
Industrie Pirelli	Pirelli General Cable	Southampton	60,000
General Electric	London Elec. Co. and Smith Ltd.	Manchester	50,000
Richard Johnson Ltd.	Johnson Nephew (non-ferrous)	Manchester	30,000
Glynwed	Wednesbury Tube Co.	W. Bromwich	25,000
United Wire Group	United Wire	Edinburgh	25,000
Metal Products	Charles Clifford	Birmingham	25,000
La Ste	E & E Kay	Enfield	10,000
McKechnie Bros.	McKechnie Metals	Aldridge	15,000
Serck Ltd.	Serck Tubes Ltd.	Birmingham	15,000

4.4.6 Fabricators

No breakdown of the structure of the copper fabricating industries has been found although the end-uses of fabricated goods have been investigated in Section 4.3.

4.4.7 Scrap Metal Merchants

Because of the wide fluctuations in copper price experienced in the past decade and the diversity of scrap merchant operators it is very difficult to accurately describe the U.K. scrap merchant structure. Certain sources, however, do provide an indication of the general size of the industry and the extent of specialisation involved and these sources are examined below.

Although all scrap metal merchants are required by law to register with their local authority (100) providing a complete but dispersed list of all scrap merchants, not all authorities allow public inspection and therefore no complete survey is possible.

The Yellow Pages in 1975 listed 3,354 metal merchants (101) and a reasonably detailed list of the merchants operating in each telephone area could be compiled, but no details of size and specialisation are available.

Trade associations are generally very helpful in providing information on the more general aspects of their members operations but, for reasons of confidentiality, cannot disclose detailed information of individual or collective capacity, costs or even materials collected. One association, the British Secondary Metals Association (BSMA) published a survey of 140 of its members in 1977 (102) and this will be discussed later. Other associations include the British Scrap Federation (generally ferrous scrap) and the Reclamation Industries Council.

A third source of information on the scrap trade is Materials Reclamation Weekly which issues an annual list of all Association members but does not indicate the comparative size and importance of these members.

Lastly, both Greene and Co. (stockbrokers (103)) and Intercompany Comparisons Ltd. (104) publish a review of the performance of the major scrap merchants, but as these companies are mostly ferrous scrap dealers their relevance to this work is limited.

Summarising, the sources listed above can provide only a limited assessment of the U.K. scrap trade in terms of size and specialisation and it may only be concluded that about 3,500 - 4,500 scrap metal merchants operate in the U.K. at present.

Because of the pyramidal structure of the U.K. industry a small number of companies tend to dominate the market. In 1975 Industrial Aids (101) listed five scrap metal merchants with a particular interest in copper, these were Brookside Metal, S.W. Wood, Tom Martin, J. Saville Gordon and Brandeis Goldschmidt. These merchants are likely to be linked, either by formal or informal ties, with the major scrap consumers to whom large parcels of scrap are sold.

It has been estimated that in 1976, the total sales of all U.K. scrap merchants was about £850 million. This was based upon the British Scrap Merchants Association (BSMA) survey (102) which also concluded that the 80/20 rule operates within the scrap industry where 20% of the companies involved in a market account for 80% of the sales volume.

A breakdown of the activities of a "typical" scrap merchant was obtained as a subjective weighted average from the BSMA survey as shown in Table 4.13. Care must be exercised in the intepretation of Table 4.13owing to the limited number of merchants and, in particular, the number of ferrous merchants covered. Nevertheless Table 4.13does show that copper accounts for 34%, or the largest percentage, of the sales value of a typical scrap merchants activities followed to lesser degrees by aluminium, ferrous and lead.

Table 4.13- Breakdown of Scrap Merchant Activities by Sales Value (calculated from data in (102))

Metal	% of sales value
Copper	34
Aluminium	18
Ferrous	15
Lead	11
Nickel	9
Stainless Steel	5
Zinc	4
Minor Metals	4
	100

4.4.8 Summary on the U.K. Copper Industry Structure

Section 4.4. has identified the dominance of the U.K. copper industry by three large vertically integrated firms, BICC, IMI and Delta whose refining and semi-manufacturing plants supply the majority of U.K. fabricators needs. These companies are also important at the level of national economy.

Scrap metal merchants were found to exhibit a pyramidal structure with small, independent merchants feeding scrap, via middle-merchants, to the large scrap merchants who are likely to be associated with the larger scrap users, i.e. BICC, IMI, Delta or Brandeis Goldschmidt.

4.5 Summary of Chapter 4

In Chapter 4 the generalised flow of copper through the U.K. was described prior to an analysis of the available statistics on these flows in Chapter 5.

The manufacturing processes employed in the various sectors of the copper industry were described with particular emphasis on the differences between the primary and secondary copper industries. It was concluded that the secondary copper industry had a more flexible structure than the primary industry which enables it to process a feedstock which varies in physical and chemical composition and to cope with the problems this variation causes.

The end-uses of copper were discussed with the major end-use being in electrical applications. It was found that the problems of compiling accurate end-use patterns for the U.K. had led to results which varied between workers, particularly with respect to tertiary uses. By using published U.K. surveys and supplementing with U.S. surveys an estimate was made of U.K. end-use patterns. The extent and nature of substitution for copper was examined and it was concluded that substitution has and will continue to occur in traditional copper markets.

Finally, the structure of the U.K. copper industry was examined and found to be dominated by three companies, BICC, IMI and Delta. The limited data on scrap metal merchant activities meant that a general description only could be given. It was found that a pyramidal structure existed and that copper is an important factor in an "average" merchants activities.

CHAPTER 5 STATISTICAL DATA ON U.K. COPPER FLOWS

5.1 Introduction

The description of UK copper flows given in Chapter 4 provides the basis for a more complex statistical description using published data on the size of the flows involved. This analysis allows the relative importance of each sector of the UK copper industry to be examined and also provides a statistical basis for the mass-balance approach to copper scrap supply and demand adopted in this work and to be developed in Chapters 7, 8 and 9.

The chapter is divided into six sections based on data availability for pre-war, wartime and post-war periods

1) The sources of statistical data on the UK copper industry are examined and their limitations identified (Section 5.2).

2) These data sources are used to derive detailed UK copper flows from 1949 to 1976 (Section 5.3).

3) Similar information is developed for the years 1922 to 1938 (Section 5.4).

4) Copper flows over the intervening period 1939 to 1948 are estimated (Section 5.5).

5) Consumption of fabricated goods over the total period considered are examined (Section 5.6).

6) The historical trends in the major UK copper flows are examined and compared to World trends (Section 5.7).

The analysis of the "pool" of copper scrap available for recycling to be developed in Chapter 8 requires data from as early a period as possible and therefore copper statistics from 1922 (the earliest year for which reasonable data was found) to 1938 were examined while the unusual copper flows over the intervening period, 1939 to 1948, were analysed separately.

Note : (ca) in Tables indicates a calculated and not measured value.

5.2 Sources of Statistics on U.K. Copper Flows

Three major statistical sources on UK copper flows were found:

1) World Metal Statistics (85)

Published monthly by the World Bureau of Metal Statistics (WBMS) World Metal Statistics gives data on (amongst others) UK copper flows from 1948 to the present. Previous titles have included Bulletin of the British Bureau of Non-Ferrous Metal Statistics (1948-1954) and Bulletin, World Non-Ferrous Metal Statistics.

2) Metal Statistics (105)

Metal Statistics is a ten yearly publication of Metallgesellschaft AG, a German company dealing in non-ferrous metals and includes data on UK copper flows. The statistics given are less detailed than in World Metal Statistics (from which Metal Statistics abstracts its data in more recent years) but this is counterbalanced by a consistency of information from 1920 onwards.

3) Census of Production (106)

The Report on the Census of Production is the most detailed statistical information available for the UK. It analyses the inputs and outputs from 153 industrial classifications and includes employment and investment in these industries. This detail is offset by publication being only every five years on average from 1907 (1907, 1912, 1924, 1930, 1935, 1948, 1954, 1958, 1963, 1968 and a current edition).

Other sources of data are available but generally they obtain their data from one of the above publications although some additional sources have been used in this analysis and are referred to when used.

While the Census of Production provides a detailed analysis of copper flows at irregular long intervals, World Metal Statistics and Metal

Statistics were found to be the only consistent annual data on UK copper flows. Metal Statistics has the advantage of providing reliable data from 1922, but this was outweighed by the fact that World Metal Statistics is available at monthly or annual intervals compared to Metal Statistics ten-yearly intervals.

It was decided that World Metal Statistics would be used where possible and Metal Statistics used for the years prior to World Metal Statistics first publication in 1948. In this case, both sources had to be compatible and Table 5.1 shows the data provided by each source for a typical year - 1972. Although there are differences in terminology, both sources agree closely in the quantities involved and it may be concluded that, using Table 5.1, they may be used to provide consistent statistics on UK copper flows from 1922 to 1976.

Table 5.1 - Comparison of Metal Statistics and World Metal Statistics Data and Terminology for the U.K. (1972) (85) (105)

World Metal Statistics - World Bureau of Metal Statistics		Metal Statistics - Metalgesellschaft A.G.	
Virgin refined production	59579	59600	Production, refined Cu from imp. blister
Secondary refined production	102456	121100	Production, refined Cu from scrap
Alloy production (gross)	112875	112900	Production, Cu Alloys
Imports: blister	52371		
Imports: refined Cu	395053	395500	Imports, refined Cu
Imports: Alloys - master alloys	201		
- alloy ingots	202	202	Imports, brass and alloys; ingots and blocks
Imports: Scrap - alloys (gross)	4679	4679	Imports, brass and alloys; scrap
Imports: Scrap - copper	13037	13037	Imports, unalloyed Cu; scrap
Exports: Refined	18821	18800	Exports of refined Cu
Exports: Alloys	45425	45103	Exports, brass and alloys; ingots and blocks
Exports: Scrap; Cu and alloy	2170	2170	Exports, unalloyed Cu; scrap
Consumption: blister	60311		
Consumption: refined	534565	535800	Apparent consumption; refined Cu
		403600	Actual cons; virgin refined Cu
		121100	Actual cons; sec. refined (=prod)
		524700	Actual cons; refined Cu
Consumption: Cu and alloy scrap (gross)	133225	124300	Direct use of scrap
Changes in stocks		+21600	Stock changes
Production: Cu semis	436720	426300	Sum; prod. of Cu and alloy prods - unalloyed.
Production: Alloy semis	270305	258400	Sum; prod. of Cu and alloy prods - alloyed
Production: Casting and Misc.	68702	68700	Sum; prod. of Cu and alloy prods -
Imports: Cu semis	14637	15523	Imports, unalloyed Cu (sum-scrap)
Imports: Alloy semis	7913	7927	Imports, brass and alloys (sum-scrap-ingots)
Exports: Cu semis	65481	66436	Exports, unalloyed Cu (sum-scrap)
Exports: Alloy semis	28022	28365	Exports, brass and alloys (sum-scrap-ingots)
Exports: Copper Sulphate	9205	9205	Exports, brass and alloys; $CuSO_4$
Exports: Powders	2989	3012	Exports, brass and alloys; powder

Notes: imp. = imports prod = production
cons = consumption sum = summation

5.3 Statistical Description of UK Copper Flows, 1949 to 1976

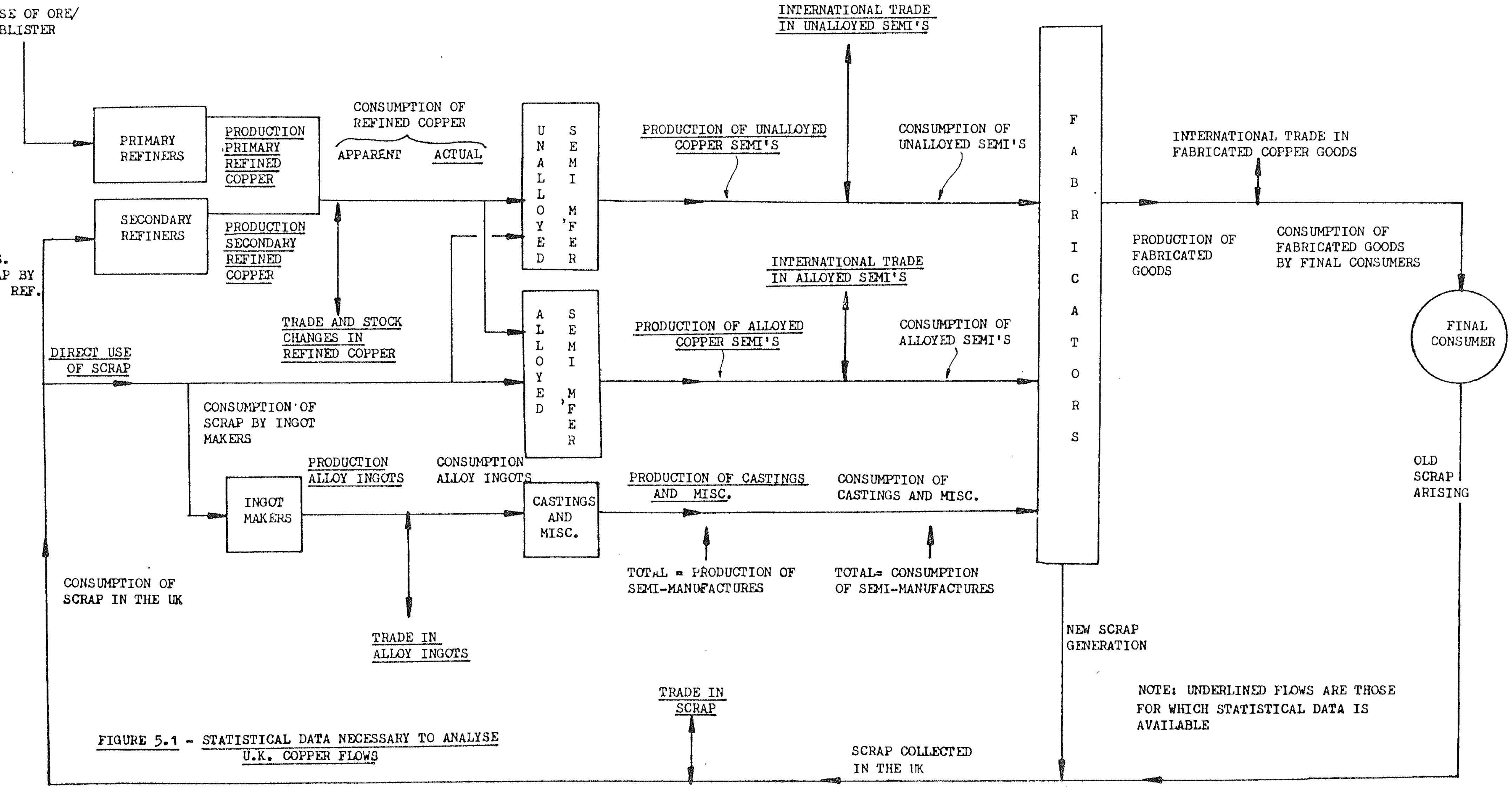
5.3.1 Introduction

As explained in the introduction to this Chapter a complete statistical description of UK copper flows is necessary to develop the mass-balance approach to the supply and demand of copper and copper scrap. The information can also be used to provide a picture of the relative flows in the UK copper industry at any point in time or to examine trends in a particular flow over a number of years.

The information provided by the statistical sources, selected in Section 5.2 and examplified in Table 5.1, is shown in Figure 5.1 overleaf (a modified version of Figure 4.1) from which it can be seen that not all the flows are statistically described. Additionally, a large proportion of the flows for which statistics are available are in terms of gross weight and not in copper content. In order to close the loop and balance net copper flows over the whole system the size of flows for which no published data is available will be calculated and additionally the copper content of the flows for which gross figures are published will be estimated.

Figure 5.1 does not show every copper flow the UK copper industry and is intended to describe the total system with the main interactions. In the following section, sectors of Figure 5.1 have been expanded and the mechanisms of calculating the necessary detailed flows described.

A major assumption used throughout the following sections is that no time lags in the manufacturing and/or fabricating processes employed in the copper industry exist, but only at the consumer stage. The high cost of copper and the economic need to avoid large stocks justify this assumption. It has also been assumed that all conversion processes, unless otherwise stated, operate at one hundred per cent efficiency. No real process works at this efficiency but lack of consistent data forces this assumption and the errors introduced are expected to be small.



NOTE: UNDERLINED FLOWS ARE THOSE FOR WHICH STATISTICAL DATA IS AVAILABLE

FIGURE 5.1 - STATISTICAL DATA NECESSARY TO ANALYSE U.K. COPPER FLOWS

These two assumptions mean that if production is known then consumption is assumed and vice-versa.

5.3.2 Refined Copper Flows

The section of Figure 5.1 concerned with refined copper flows has been isolated and expanded in Figure 5.2 below. As in Figure 5.1 the copper flows for which data are available have been underlined and additionally reference numbers are given to each flow to illustrate the methodology employed in this and later sections.

All primary refined copper production (2) is from imports of copper matte, concentrate and blister (1) (see Section 4.2.2) and it is interesting to note that this is the one process for which both input and output data are available and that these flows do not balance, for example by a deficit of 7000 tonnes in 1972 from a primary refined production level of 59,600 tonnes. Three years later however, the deficit turned to a surplus with 1975 imports of matte, concentrate and blister being 82,600 tonnes or

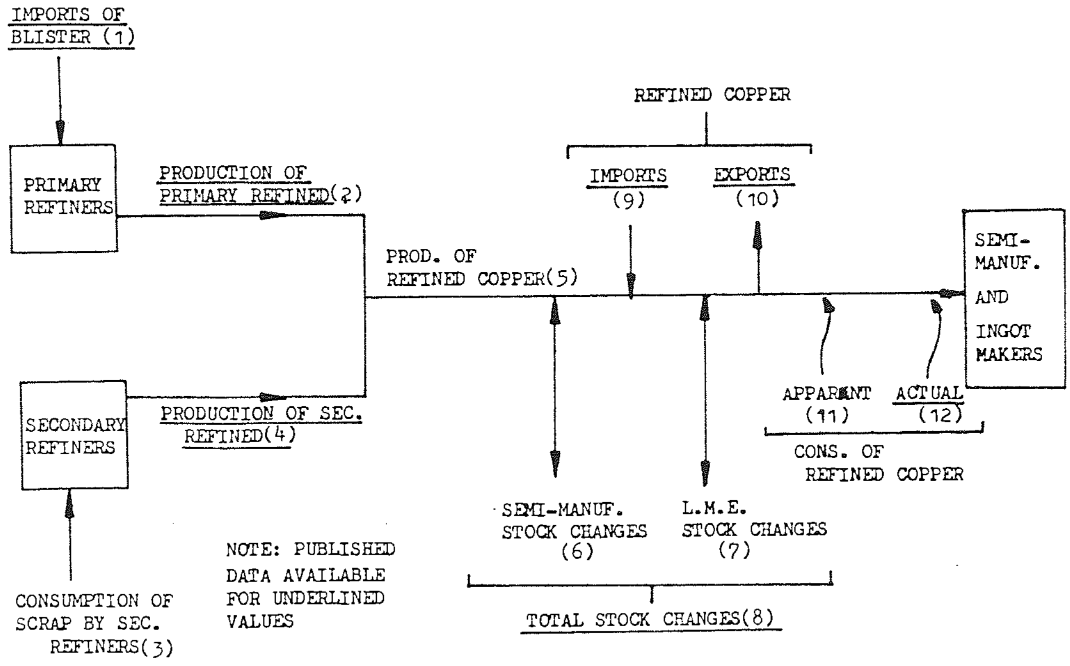


Figure 5.2 - UK Refined Copper Flows

7000 tonnes more than the production of primary refined copper. The difference is normally relatively small and probably attributable to the inability of refiners to distinguish between primary and secondary production. It has therefore been ignored, and the Production of primary refined copper (2) has been used.

The calculations used to compile the copper flows in Figure 5.2 as summarised in Table 5.2 are given below:-

Consumption of scrap by secondary refiners (3) = Production of secondary refined copper (4) (See 3·4·1. 100% efficiency assumed)

Production of refined copper (5) = Production of primary refined copper (2) + Production of secondary refined copper (4)

Apparent consumption of refined copper (11) = Production of refined copper (5) + Imports of refined copper (9)
- Exports of refined copper (10) + Total Stock changes (8)

Total Stock Changes (8) = Semi-manufacturers stock changes (6) + LME warehouse stock changes (7)

There are two measures of the consumption of refined copper by the semi-manufacturers. The first is the apparent consumption (11) which is calculated by the method given above. The second measure is the reported consumption by the semi-manufacturers, termed the actual consumption (12). Table 5.2 shows that over the period 1949 to 1976 the surplus of actual consumption over apparent consumption was 368,000 tonnes or approximately 3 per cent of annual actual refined consumption. This is not considered significant and cannot be explained by the assumptions of no time-lags and one hundred per cent process efficiencies; it shows the inconsistency in the reported statistics which may have an adverse effect on the accuracy and validity of subsequent modelling techniques.

The methodology described in detail above was repeated for the other sectors of Figure 5.1.

Table 5.2 - U.K. Refiners Copper Flows (tonnes x 10^3)

Year	P.Primary Refined	P.Sec Refined	Imports	Exports	Stock Changes	App. Cons. (ca)	Actual Cons. (ca)	Diff (ca)
1949	106.8	73.6	193.3	0.8	-1.5	374.4	399.4	-25.0
1950	121.2	72.0	214.8	0.3	-10.1	417.8	412.7	5.1
1951	134.2	75.0	228.3	0.5	14.5	422.5	410.7	11.8
1952	148.8	80.1	215.5	0.8	4.4	439.2	433.3	5.9
1953	98.5	89.6	231.2	21.8	75.4	322.1	337.0	14.9
1954	138.7	83.9	272.1	26.3	8.8	459.6	457.5	2.1
1955	125.5	105.3	291.0	26.9	10.9	484.0	508.5	-24.5
1956	115.6	104.3	298.6	49.5	-11.3	480.3	511.1	-30.8
1957	114.1	90.4	355.9	48.5	25.8	486.1	516.1	-30.0
1958	99.9	96.4	368.5	59.7	-21.0	526.1	548.1	-22.0
1959	97.1	98.3	346.7	01.5	-6.0	446.6	501.1	-54.5
1960	112.7	106.2	442.8	56.6	53.6	551.5	565.2	-13.7
1961	131.1	107.0	393.5	79.7	13.5	538.4	540.6	-2.2
1962	118.8	112.9	428.4	122.5	18.2	519.4	542.9	-23.5
1963	91.4	109.1	399.8	58.6	1.2	540.5	563.8	-23.3
1964	112.5	112.4	425.1	39.1	1.0	609.9	635.9	-26.0
1965	102.8	124.8	488.3	47.0	4.0	664.9	657.3	7.6
1966	43.8	136.0	473.2	54.8	5.8	592.4	594.1	-1.7
1967	35.9	133.4	419.6	62.4	8.4	534.9	528.1	6.8
1968	49.7	148.0	416.3	56.3	9.2	548.5	550.7	-2.2
1969	49.3	148.9	416.7	67.6	-4.5	551.8	546.8	5.0
1970	49.4	156.8	409.5	44.9	13.4	557.4	553.7	3.7
1971	49.5	138.1	366.1	28.1	13.7	511.9	511.3	0.6
1972	59.6	121.1	395.5	18.8	21.6	535.8	529.7	6.1
1973	75.8	108.5	399.4	66.1	-49.7	567.3	545.6	21.7
1974	69.1	91.0	380.9	35.0	10.0	496.0	528.1	-32.1
1975	75.5	76.0	369.0	15.7	57.2	447.6	513.1	-65.5
1976	51.6	85.7	367.9	12.3	22.7	470.2	522.8	-52.6

Note: (ca) = calculated value

5.3.3 Semi-Manufacturers Copper Flows

The copper flows to and from the semi-manufacturers are summarised in Figure 5.3 below. The semi-manufactures from the focal point of the copper industry as they produce alloyed and unalloyed copper shapes from refined copper and scrap (including ingot) which are then fabricated to produce goods for consumption by end-users. In Section 5.3.2 the refined copper flows involved were relatively simple and well defined by published statistics. The flows in this section are more detailed and therefore require the use of justified assumptions. Semi-manufacturers are produced in four main shape groups as shown in Table 5.3 below.

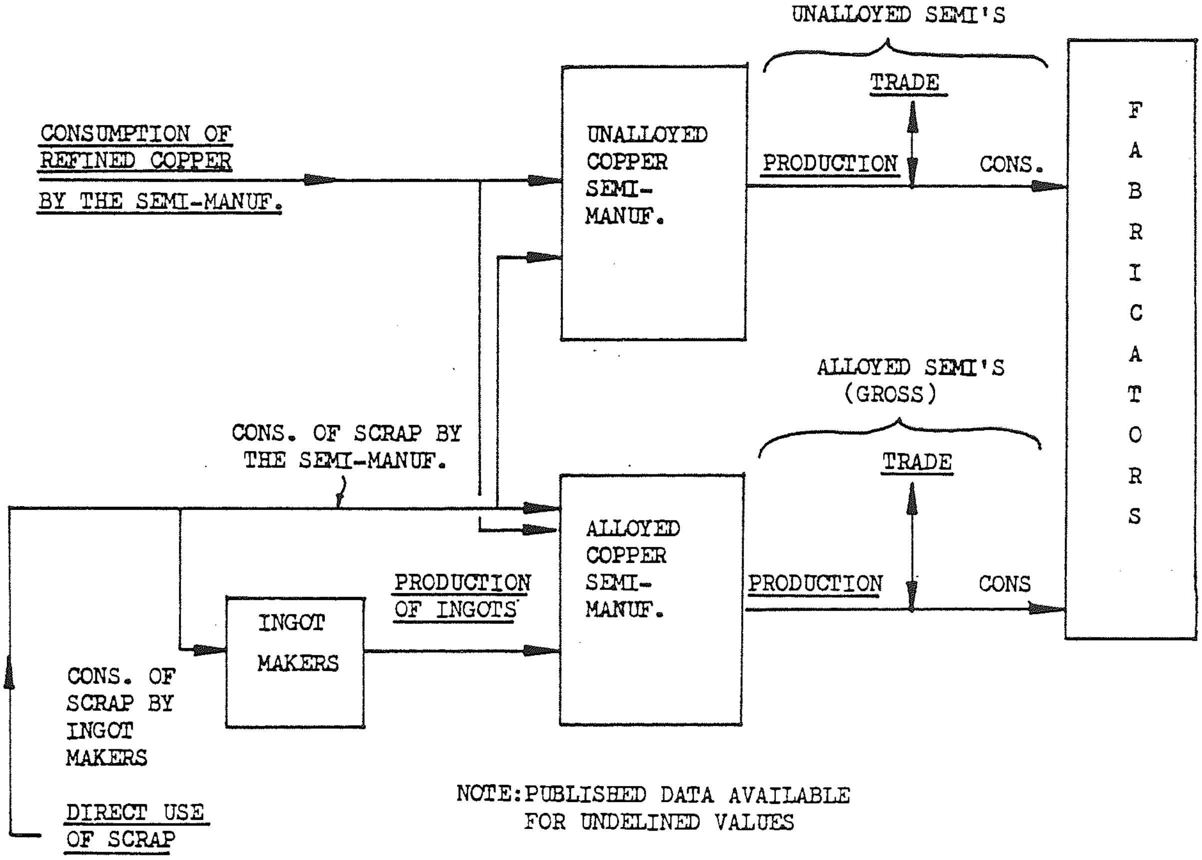


Figure 5.3 - Flows of Copper to and from the Semi-Manufacturer

Table 5.3 - Major Semi-Manufacture Shape Groups

Wire
Rod, bar and sections
Sheet, strip and plate
Tube

These shapes are produced both in unalloyed and alloyed copper. In the case of alloyed copper a fifth and sixth group, castings and miscellaneous products (copper sulphate, powders etc.) must be considered.

Semi-manufactures are produced from refined copper and a mixture of new, old and prompt industrial scrap. The prompt industrial scrap, as described previously (Chapter 2) may be treated as a constantly circulating stock and so may be disregarded. The remaining new and old scrap are listed together under the heading of direct use of scrap.

Analysis of the production and international trade in unalloyed copper semi-manufactures is uncomplicated as the products are essentially 100% copper reflecting the extensive use of refined copper in their production.

Alloy semi-manufactures production and trade is more difficult as it is necessary to estimate the copper content of the alloys produced from the published gross figures. Unlike Metal Statistics (85), World Metal Statistics (105) gives both the gross tonnages and the net copper content of the shape groups involved for recent years. From this data can be calculated the average copper content of each shape group. By assuming that these copper contents have not varied widely over the period in question then they may be applied to the gross figures for earlier years. These average copper content figures are given below in Table 5.4 and from this point on, all statistics, unless stated otherwise, will be in terms of the copper content.

Table 5.4 - Average Copper Content of Various Alloy Semi-Manufacture Shape Groups

Shape Group	Average Copper Content (%)
Wire	75
Rod, Bar and Sections	61
Sheet, Strip and Plate	68
Tube	70
Castings and Misc.	82
Weighted average	68

Referring to Figure 5.3 it can be seen that the total production of semi-manufactures equals the sum of unalloyed semi's production and the copper content of the alloy semi's production. This figure is then used to calculate the direct use of scrap which equals the difference beteween the total production of semi's and the actual consumption of refined copper.

The consumption of semi's by the fabricators (Figure 5.3) is obtained by allowing for trade in semis for which data is available in gross terms and which can be corrected for copper content using the figures given in Table 5.4.

The flows of unalloyed and alloyed copper semi-manufactures are summarised in Table 5.5.

Table 5.5 - Summary of Semi's Production Statistics (tonnes x 10^3)

Year	Unalloyed	Alloyed (a)	Total
49	303	195	498
50	301	223	524
51	295	253	548
52	312	252	564
53	242	200	442
54	326	249	575
55	375	282	657
56	380	247	627
57	406	231	637
58	442	226	668
59	381	253	634
60	434	291	725
61	416	270	686
62	409	245	654
63	428	260	688
64	497	293	791
65	522	285	807
66	472	263	735
67	414	235	649
68	415	260	675
69	416	273	689
70	420	252	672
71	404	223	627
72	426	222	649
73	454	247	700
74	427	233	660
75	386	186	570
76	404	199	602

Note (a) copper content.

5.3.4 Fabrication Industries Flows

The basic flows through the fabrication industries are shown in Figure 5.4 below and are an important element in closing the loop of copper flows to and from the consumer.

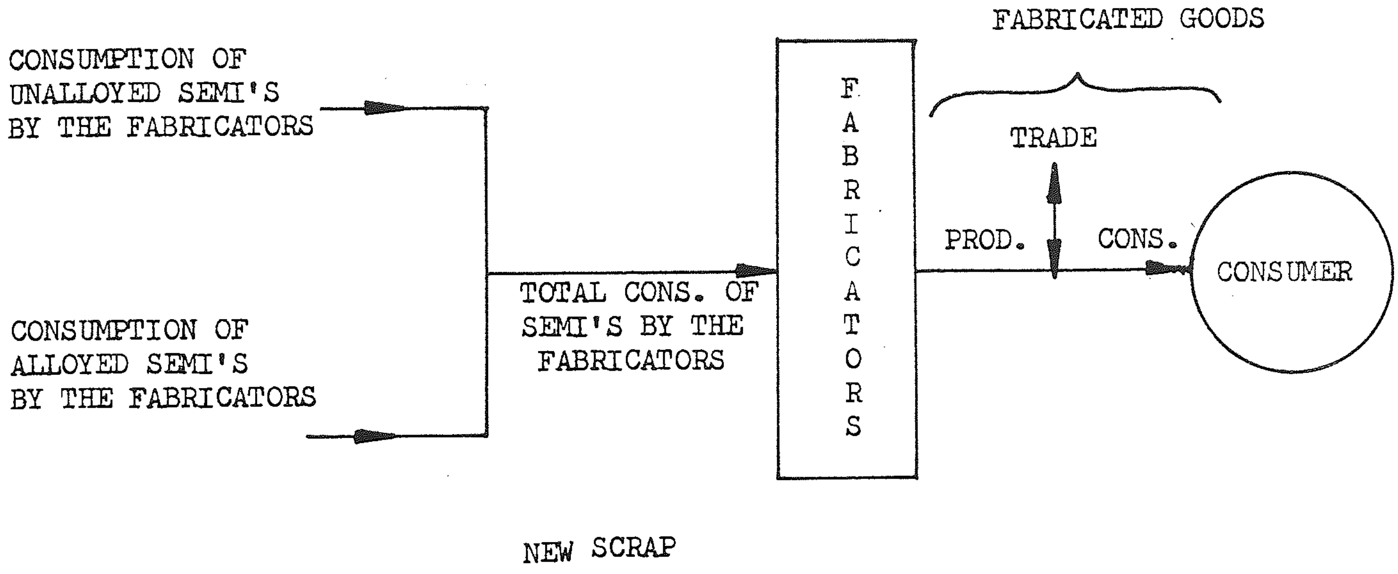


Figure 5.4 - Flows of Copper to and From the Fabricators

No published data is available on the flows involved in Figure 5.4 although the inputs to the fabricators may be calcualted as already described in the previous section.

The estimation of the production of fabricated goods and the generation of new scrap provide the main problem in "closing the loop" of UK copper flows (see Figure 5.1) as, unlike the more developed statistics for the U.S.A., the quantity of new scrap generated is not published and in fact, from discussions with various workers interested in this problem, no definitive work has been carried out to determine its size. Various authors have estimated the ratio of new scrap to fabricated output to be anything from 1:1 to 1:9 (i.e. 50% of fabricator inputs to 10%. of fabricator inputs) (86,88,107). The American figures cannot be used; firstly because of technological differences and secondly because of the problems of compatability between American and U.K. Statistics.

Tron (107) approached the problem by using average fabrication efficiencies as described by Dyson (108) and defined as the percentage of the input of a shape group to a fabrication process to be found in the output of that process. Various fabrication efficiencies are given in Table 5.6 below, where it can be seen that, as expected, castings have the highest fabrication efficiencies followed by wire and tube (which are very similar shapes) and finally sheet, strip and plate together with rod, bar and section.

Table 5.6 - Average Fabrication Efficiencies for Various Shape Groups (108)

Shape Group	Fabrication Efficiency (%)
Wire	75
Rod, bar and section	52
Sheet, strip and plate	67
Tube	73
Castings	88

By applying these fabrication efficiencies to the consumption of the various shape groups by the fabricators it is possible to estimate both the production of fabricated goods and the generation of new scrap.

Statistics on the international trade in fabricated goods is difficult to obtain. Tron (107), after analysing the 1968 Census of Production (106), estimated that 32% of U.K. fabricated goods production is exported and that 17% is imported resulting in a net export of 15%. Alexander (88) assumed a figure of 10%. This indicates that 10% is a

Table 5.7 - Copper Flows to and From Copper Fabricators (tonnes x10^3)

Year	Semis cons. by fabricators (ca)	Production of fabricated goods (ca)	New Scrap generation (ca)	Final cons. of fabricated goods (ca)
1949	437.4	309.1	128.3	278.2
1950	463.0	321.9	141.1	289.7
1951	516.4	362.3	154.1	326.0
1952	535.5	376.8	158.7	339.1
1953	411.6	289.7	121.9	260.8
1954	527.8	372.9	154.9	335.6
1955	592.4	416.5	175.9	374.8
1956	531.4	378.1	153.3	340.3
1957	528.0	379.2	148.8	341.3
1958	532.1	381.4	150.7	343.3
1959	566.8	403.5	163.3	363.2
1960	652.5	469.5	183.0	422.5
1961	633.5	452.7	180.7	407.5
1962	608.9	436.7	172.2	393.1
1963	646.6	460.7	185.9	414.6
1964	746.7	530.0	216.8	477.0
1965	745.7	532.5	213.1	479.3
1966	668.6	478.3	190.3	430.4
1967	591.2	422.6	168.7	380.3
1968	619.3	439.2	180.0	395.3
1969	622.5	444.2	178.3	399.8
1970	594.9	428.8	166.1	385.9
1971	543.5	396.4	147.1	356.8
1972	581.9	421.5	160.4	379.4
1973	617.5	448.7	168.8	403.8
1974	600.8	432.6	168.3	389.3
1975	503.9	369.3	134.6	332.4
1976	543.6	394.5	149.0	355.1

Note : (ca) = calculated value

reasonable figure to use. Consequently, the production of fabricated goods in the U.K. has been reduced by 10% to allow for international trade enabling the consumption of fabricated goods in the U.K. to be calculated.

The production of fabricated goods is given in Table 5.7 together with the final consumption of fabricated goods and the production of new scrap. Trade in fabricated goods has not been given as it is a constant proportion of semis production.

5.3.5 Scrap Flows

The final step in closing the loop of material flows in Figure 5.1 is the description of the flow of goods after use by the consumer (and fabricator) as illustrated in Figure 5.5. below. The constantly recirculating flows of home scrap at the semi-manufacturers have not been included in this analysis.

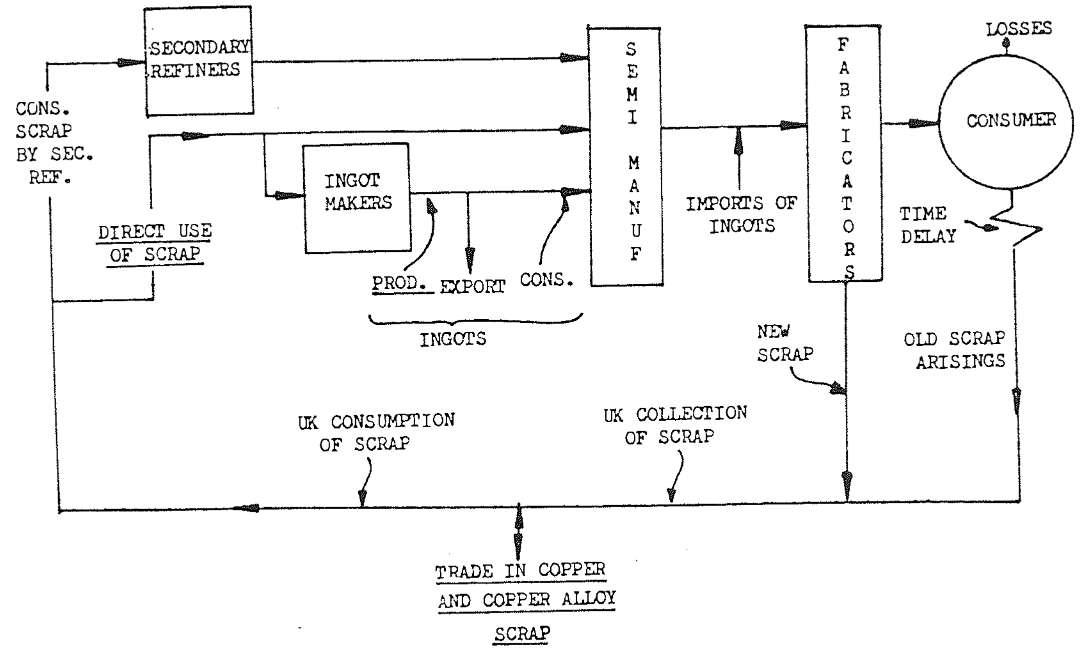


Figure 5.5 - Major Flows of Copper Scrap in the U.K.

Once the fabricated goods delivered to the consumer have finished their useful life they are discarded and arise as 'old' scrap which may or may not be recovered. A more detailed description of the estimation of old scrap arisings is presented in Chapter 8. The old scrap that is collected is combined with the 'new' scrap from the fabrication process and is termed the collection of scrap in the U.K.

Not all this scrap is recycled within the U.K; there is a certain amount of international trade in copper and copper bearing scrap, the alloy copper content of which may be estimated by correcting the published gross figures by the weighted average copper content figure of 68% given in Table 5.4 earlier. This assumes that the alloy scrap imported or exported not unreasonably reflects U.K. semi's production figures. The corrected scrap collection figure is termed the consumption of scrap in the U.K. and this scrap may be used in one of two ways. Firstly, it may be used for the production of secondary refined copper and its consumption in this use is, as explained in Section 5.3.2, assumed to equal production of secondary refined copper. Secondly, it may be used directly in the production of semi's (the Direct Use of Scrap) although a proportion is used by the ingot makers. Statistics on the production of alloy ingots are available and consumption of scrap in this use is assumed to equal production of ingots although a small, unknown quantity of refined copper is known to be used as well. Before the ingots progress to the semi-manufacturing stage international trade takes place, on which statistics in gross terms are available and from which the copper content may be extracted by the use of the relevant copper content figure from Table 5.4. Tron (107) after discussions with ingot makers and consumers concluded that imports of ingots are consumed directly by the fabricators of the castings and miscellaneous shape groups and this assumption has been built into this analysis.

Examination of Figure 5.5 and published statistics reveals an interesting point concerning the estimation of scrap consumption in the U.K. That is, that the direct use of scrap is a calculated and not a measured figure which is obtained by the difference beteween the copper content of the production of semis and the actual consumption of refined copper. Calculated in this way, the direct use of scrap fails to take into account the exports of alloy ingots, assuming that they are produced from scrap. It is therefore necessary to correct the figure for the direct use of scrap by the addition of the copper content of the alloy ingots exported.

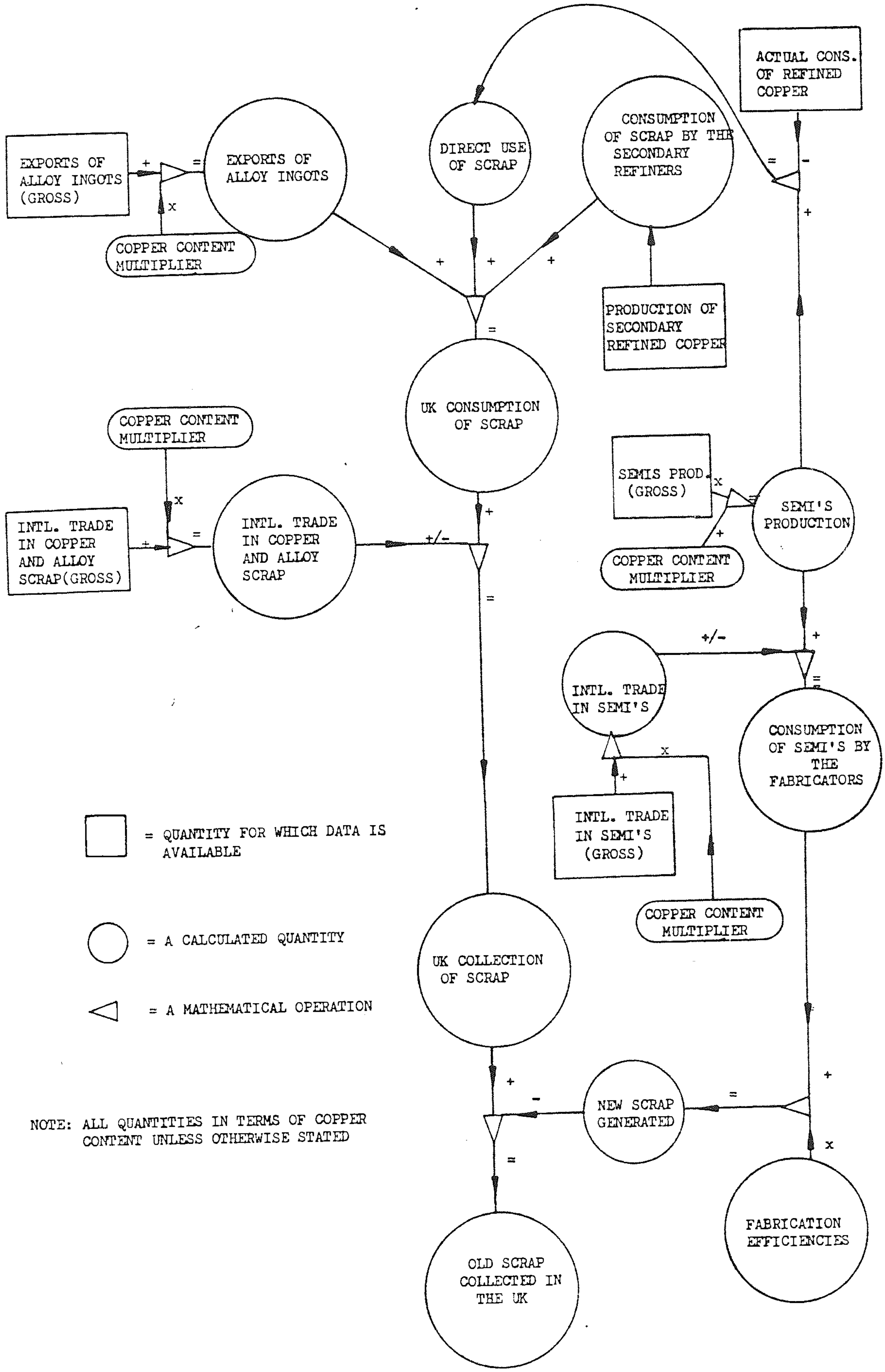
The evidence available on the flows of copper scrap in the U.K. is very limited, the only directly measured data available is that on the international trade that takes place in copper scrap.

Figure 5.6 shows the major calculations involved in statistically describing U.K. scrap copper flows, the results of which are summarised in Table 5.8.

5.3.6 Summary of U.K. Copper Flows - 1976

Detailed statistics on U.K. copper flows have been developed while Figure 5.7 shows the relative size of these flows for the latest year described, 1976. The historical trends in these flows will be analysed in Section 5.4.

Figure 5.7 shows that U.K. refined copper supplies in 1976 were primarily from imports supplemented by secondary refined copper and, to a lesser extent, primary refined copper. Figure 5.7 also illustrates the pattern of semis production described in Figure 4.5 earlier with production of unalloyed wire being the major semi produced, followed by alloyed rod/bar. The pattern of semis consumption by the fabricators is similar owing to a small international trade in semis. Scrap flows are



NOTE: ALL QUANTITIES IN TERMS OF COPPER CONTENT UNLESS OTHERWISE STATED

FIGURE 5.6 - MAJOR CALCULATIONS INVOLVED IN THE CALCULATION OF UK SCRAP FLOWS

Table 5.8 – Scrap Flow – Summary Table (copper content) (tonnes x 10^3)

Year	Prod sec.ref.	Direct Use (ca)	Exports ingots	UK cons. of scrap (ca)	Nett trade in scrap	UK collected scrap (ca)	New Scrap (ca)	Old Scrap (ca)
1949	73.6	108.5	16.9	199.0	+0.4	198.6	128.3	70.3
1950	72.0	125.0	17.0	214.0	-2.2	216.2	141.1	75.1
1951	75.0	149.6	5.0	229.6	+1.7	227.9	154.1	73.8
1952	80.1	151.8	4.8	236.7	+0.6	236.2	158.7	77.5
1953	89.6	126.9	14.8	231.3	+1.7	229.6	121.9	107.7
1954	83.9	132.8	7.4	224.1	+15.3	208.8	154.9	53.9
1955	105.3	163.6	9.9	278.8	+19.4	259.4	175.9	83.5
1956	104.3	133.7	17.5	255.5	+3.0	252.6	153.3	99.3
1957	90.4	136.1	19.0	245.5	+3.0	242.6	148.8	93.7
1958	96.4	135.4	22.8	254.6	+0.2	254.5	150.7	103.7
1959	98.3	156.8	21.2	276.3	+0.8	275.5	163.3	112.2
1960	106.2	173.9	20.3	300.4	+4.6	295.8	183.0	112.8
1961	107.0	167.0	26.0	300.0	+0.4	299.5	180.7	118.8
1962	112.9	138.3	32.2	283.4	+1.7	281.6	172.2	109.4
1963	109.1	137.5	27.4	274.0	-9.1	283.1	185.9	97.2
1964	112.4	164.8	24.5	301.7	-0.7	302.3	216.8	85.6
1965	124.8	164.9	23.5	313.2	-7.9	321.1	213.1	107.9
1966	136.0	150.0	29.4	315.4	-6.7	322.1	190.3	131.8
1967	133.4	138.1	39.2	310.7	-1.1	311.8	168.7	143.2
1968	148.0	140.5	33.1	321.6	+4.6	317.0	180.0	137.0
1969	148.9	143.6	31.5	324.0	+4.9	319.1	178.3	140.8
1970	156.8	119.9	30.7	307.4	+7.8	299.6	166.1	133.5
1971	138.1	117.0	27.0	282.1	+8.8	273.3	147.1	126.2
1972	121.1	124.3	30.7	276.1	+14.0	262.1	160.4	101.7
1973	108.5	153.3	29.0	290.8	+7.9	282.9	168.8	114.0
1974	91.0	164.1	24.9	280.0	-16.8	286.8	168.3	128.5
1975	76.0	124.4	22.5	222.9	-35.5	248.5	134.6	113.9
1976	85.7	147.0	18.6	251.3	-20.9	272.2	149.0	123.2

Note: (ca) = calculated value.

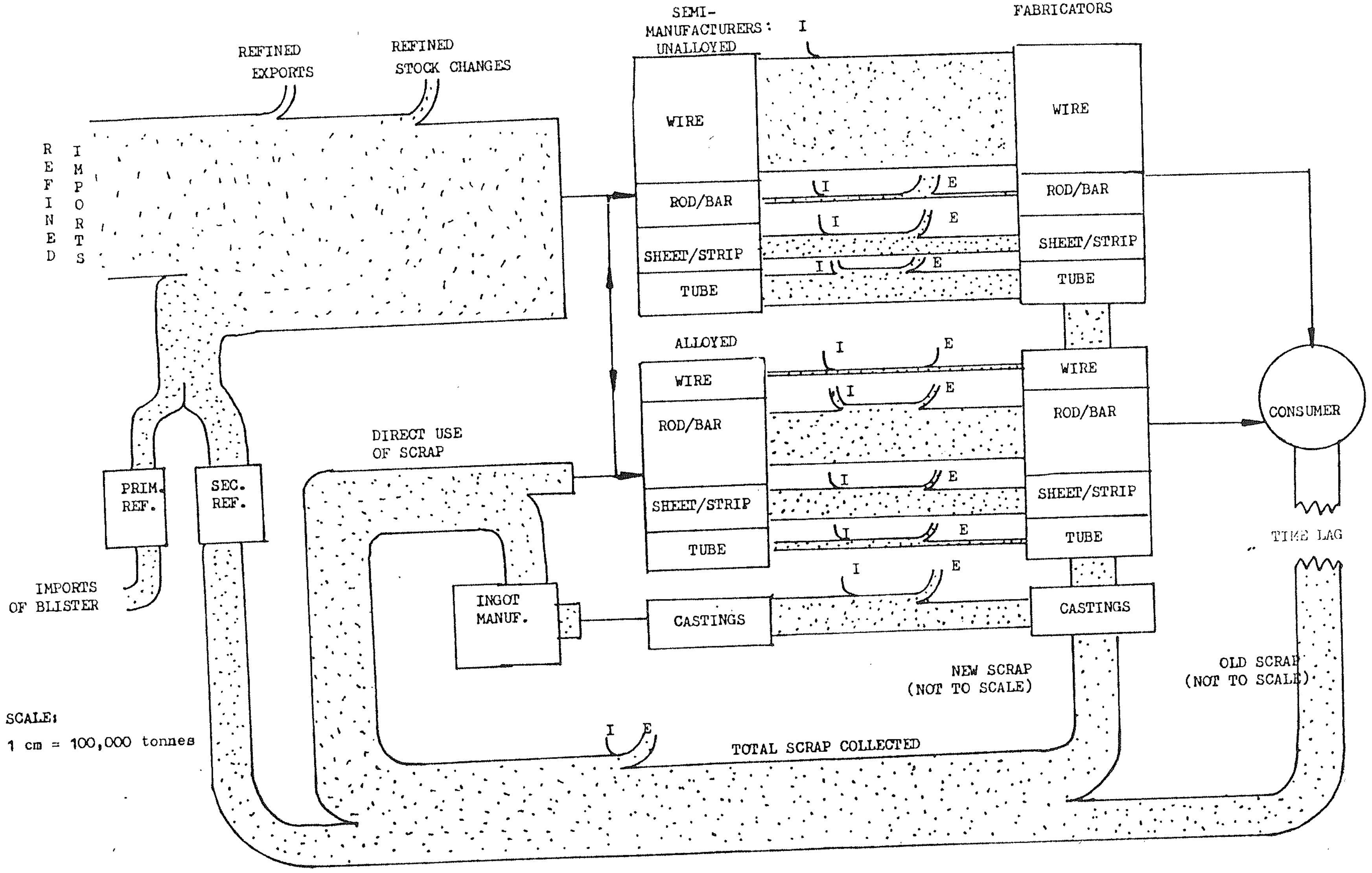


FIGURE 5.7 - COPPER CONTENT OF UK COPPER FLOWS, 1976

Notes : I = Imports
E = Exports

significant, with only small international trade, but it is interesting to note that secondary refining accounts for about one third of all scrap flow with the remainder or the direct use of scrap, being equally divided between ingot manufacture and the true direct use of scrap by the semi-manufacturers.

The gaps in Figure 5.7 highlight the need for more detailed statistics on U.K. copper flows with particular reference to new and old scrap flows and the direct use of scrap, but this should not distract from the usefulness of the statistics involved which, for the flows considered, accurately and completely describe the U.K. copper flows over the period considered.

5.4 Statistical Description of U.K. Copper Flows 1922 - 1938

The statistics on copper flows available for the period 1922-1938 are not as complete as those for 1949-1976 and are generally limited to information on the flows of refined copper and trade in semi-manufacturers as underlined in the simplified copper flow chart, Figure 5.8. The significance of this pre-war data is primarily with the considerable time lags inherent in the consumer sector of the system and will be used in this context in Chapter 8.

It is however, possible to derive some further flows in the simplified cycle of Figure 5.8 in order to compare the pre-war copper industry with that of the post-war years. Of particular interest is the consumption of fabricated goods. This will be derived from data on the actual consumption of refined copper and international trade in semi's together with appropriate assumptions derived from post-war information. The methodology employed is shown in Table 5.11 and the description of the derivation of the flows involved is designed to follow Table 5.11 with the letters below referring to the columns in the table.

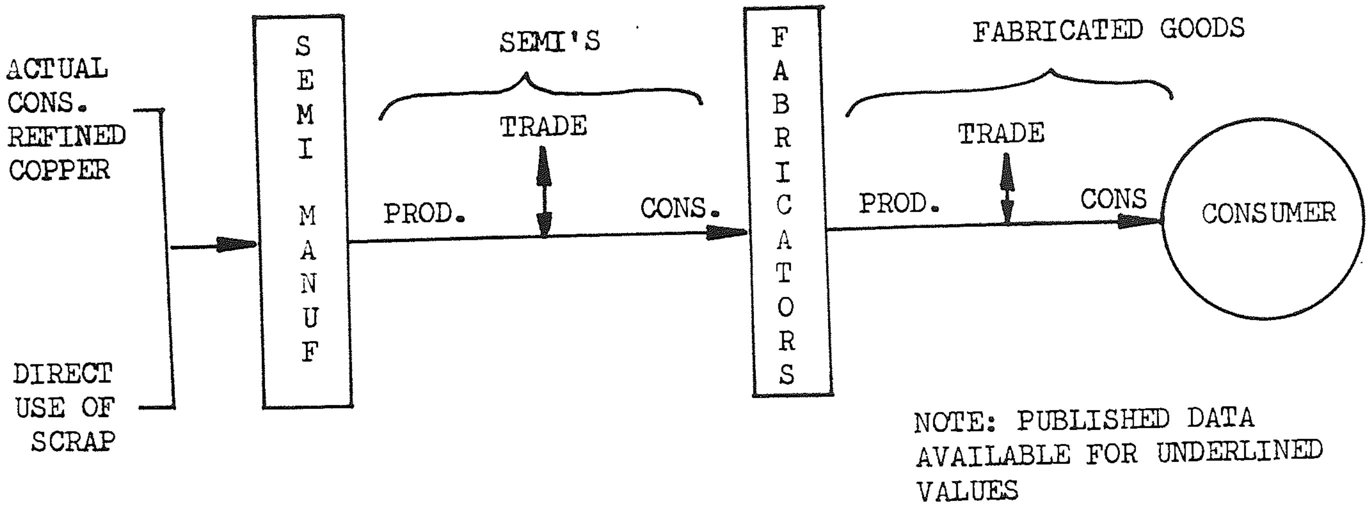


Figure 5.8 - U.K. Copper Flows Needed to Calculate the Consumption of Fabricated Goods, 1922-1938

a) Metal Statistics provides the actual consumption of refined copper but listed under the heading of "consumption of refined copper including stock changes". This was checked by referring to the Annual Abstract of Statistics (109) which used Ministry of Supply statistics, a data source also used by Metal Statistics over some common years

b) In order to calculate semis production, for which no data is available the ratio between the direct use of scrap and the production of semis was used. The direct use of scrap is itself difficult to ascertain. As described in Section 5.3.5 the direct use of scrap is obtained by subtracting the actual consumption of refined copper from the copper content of the semi-manufactures produced. As explained above no data could be found for semis production but Table 5.9 shows the percentage of semis production attributable to the direct use of scrap for the years 1949 to 1976.

Table 5.9 - Percentage of Semi's Production from the Direct-Use of Scrap 1949 - 1976

Year	%	Year	%	Year	%	Year	%
1949	22	1956	21	1963	20	1970	18
1950	24	1957	21	1964	21	1971	19
1951	27	1958	20	1965	22	1972	19
1952	27	1959	25	1966	20	1973	22
1953	29	1960	24	1967	21	1974	25
1954	23	1961	24	1968	21	1975	22
1955	25	1962	21	1969	21	1976	24

The average value is 22.4% with a standard deviation of 2.7%. No obvious trend is observed and indeed, it would be dangerous to draw conclusions about possible trends from the above data because, (Section 5.3.5), the direct use of scrap is an artificial figure with no statistical base.

Alexander (88) used a figure of 25% in his survey of this period and, as this agreed closely with the average figure from Table 5.9 a figure of 25% was used for the 1922 - 1938 period. This was used to calculate semis production as being equal to 1.33 times the actual consumption of refined copper. No evidence of a significant secondary refining industry prior to World War II has been found.

c) The nett trade in semis is obtained from Metal Statistics in gross terms for each shape group and corrected for copper content according to the factors given in Table 5.4.

d) The consumption of semis by the fabricators may then be calculated (See Figure 5.8).

e) The production of fabricated goods cannot be determined in the same way as for the period 1949 to 1976 as the flows of individual shape groups are not available. Table 5.10 gives the overall fabrication efficiencies for the period 1949-1976 and although there appears to be a very slight upward trend, possibly due to technological progress, the average figure of 71.4% is considered relevant to the period 1922 to 1938, enabling the production of fabricated goods to be calculated.

Table 5.10 - Average Fabrication Efficiencies (1949 - 1973) for the U.K. Copper Fabricators

Year	%	Year	%	Year	%	Year	%
1949	71.0	1956	72.0	1962	71.7	1968	70.5
1950	69.8	1957	72.5	1963	71.3	1969	71.4
1951	70.2	1958	72.7	1964	71.0	1970	72.1
1952	70.4	1959	71.3	1965	71.4	1971	73.0
1953	70.4	1960	71.9	1966	71.6	1972	72.5
1954	70.7	1961	71.4	1967	71.5	1973	72.7
1955	70.7						

f) Trade in fabricated goods is an uncertain quantity for the 1949 to 1976 period and is even more nebulous for this earlier period. The only other work found on this period was by Alexander (88) who assumes a figure of 10% nett exports and this agrees well with the estimate of 15% nett exported used for the 1949 - 1976 period. The lower estimate of 10% was used as discussions with Tron and Alexander indicating that this would be the more realistic figure for the period in question. Using this figure the consulmption of fabricated goods may be calculated (Table 5.11).

Table 5.11 - Summary Statistics : U.K. Copper Flows 1922 - 1938

Year	Actual Consumption or refined copper(a)	Semis Production (Cu content) (b)	Nett trade in semis (c)	Consumption of semi-manufactures by fabricators (d)	Production of fabricated goods (e)	FINAL CONSUMPTION OF FABRICATED GOODS = (f)
1922	39.9	53.2	-23.2	30.0	21.4	19.3
1923	96.6	128.8	-18.6	110.2	78.7	70.8
1924	131.8	175.7	-19.2	156.5	111.7	100.6
1925	127.7	170.2	- 7.5	162.7	116.2	104.6
1926	137.3	183.0	-11.3	171.7	122.6	110.3
1927	155.3	207.0	-12.6	194.4	138.8	124.9
1928	158.6	211.4	-10.5	200.9	143.4	129.1
1929	153.8	205.0	- 3.3	201.7	144.0	129.6
1930	150.6	200.8	+10.9	211.7	151.2	136.0
1931	123.1	164.1	+20.3	184.4	131.7	118.5
1932	120.0	160.0	- 3.6	156.4	111.7	100.5
1933	149.0	198.6	-14.1	184.5	131.7	118.6
1934	222.7	296.9	- 9.7	287.2	205.1	184.6
1935	244.0	325.3	-16.1	309.2	200.8	198.7
1936	262.0	349.3	- 1.8	347.5	248.1	223.3
1937	307.2	409.5	- 7.6	401.9	287.0	258.3
1938	262.2	349.5	- 4.1	345.4	246.6	222.0

(a) Metallgesellschaft (105): equals actual consumption of refined copper
(b) Equal to 1.33 times the actual consumption of refined copper
(c) Metallgesellschaft (105): -ve indicates nett exports; +ve nett imports
(d) = (a) + (b) + (c)
(e) = (d) x 0.714
(f) = (e) x 0.9

5.5 Statistical Description of U.K. Copper Flows 1939 - 1948

The period 1939 - 1948 is the most difficult on which to obtain statistics as none were published during World War II and those published later for the war period are incomplete, particularly with respect to the international trade in semi-manufactures.

In this section, the available statistics are analysed and certain assumptions made to facilitate the calculation of the U.K. consumption of fabricated goods. The lack of complete and accurate published statistics has resulted in statistics on copper flows for this period being taken from the two sources available i.e. Metal Statistics (105) and the Annual Abstract of Statistics (109). While agreeing on the size of many flows the two sources cover different periods which may overlap providing cross-checks on the accuracy of the statistics. The following methodology was adopted with reference to the columns of Table 5.12:-

a) A similar approach to the 1922-1938 period was adopted starting with data on the "home consumption of virgin refined copper" (= Actual consumption of primary refined copper) taken from AAS as shown in Table 5.12.

b) During World War II (1939 - 1945) a secondary refining industry was established in the U.K. for which statistics are available only from 1942 when 168,400 tonnes were produced. It is unlikely that such a large volume of production commenced in a single year and so secondary refined production has been assumed to have grown linearly from zero in 1939 to its 1942 level, as shown in Column (b) of Table 5.12.

c) As in the 1922-1938 period no data is available on the direct use of scrap for the years 1939 to 1944 and so the assumption adopted in Section 5.4, i.e. that an average of 25% of semi production arises from the direct use of scrap, has been adopted.

Table 5.12 - Development of U.K. Copper Statistics 1939 to 1948

Year	Home Consumption, Virgin Refined copper (a)	Production of secondary refined copper (b)	Direct use of scrap (c)	Nett trade in semis (d)	Consumption of semis by fabricators (e)	Production of fabricated goods (f)	Final consumption of copper goods (g)
1939	297.5	0	99.0	-33.0	363.5	259.5	233.6
1940	453.5	55.0	167.8	-67.6	608.7	434.6	391.1
1941	457.2	110.0	187.2	-75.4	679.0	484.8	436.3
1942	498.6	168.4	220.1	-88.7	798.4	570.1	513.1
1943	455.8	200.4	216.5	-87.3	785.4	560.8	504.7
1944	353.7	160.4	169.7	-68.4	615.4	439.4	395.5
1945	293.2	52.4	123.3	-18.3	450.6	321.7	289.6
1946	330.7	75.0	96.0	-75.7	426.0	304.2	273.8
1947	355.7	74.2	119.6	-53.1	496.4	354.4	319.0
1948	362.5	68.7	116.1	-51.5	495.8	354.0	318.6

(a) From Annual Abstract of Statistics (109) = Actual Consumption of primary refined copper

(b) 1939 - 1941: secondary refined production assumed to grow linearly from zero at the outset of WWII to the level shown for 1942.
1942 - 1944: calculated as the difference between the copper content of the total (i.e. secondary refined and direct use) consumption of scrap (from Annual Abstract of Statistics, 1951 (109)) and the calculated direct use of scrap (c).
1945 - 1948: Metal Statistics (105).

(c) 1939 - 1944: Assumed to equal 33.3% (see text) of the Home Consumption of "Virgin Refined Copper" (a).
1945 - 1948: Metal Statistics (105).

(d) 1939 - 1944: Assumed to equal 10% of semis production (see text) (= home consumption virgin refined copper and production of secondary refined copper and direct use of scrap).
1945 - 1948: Metal Statistics (105).

(e) = (a) + (b) + (c) + (d).

(f) Assuming an average fabrication efficiency of 71.4% (see text).

(g) Assuming a nett trade figure of 10% exported.

(h) Underlining indicates that published data is available for the flows involved.

d) Data on the trade in semi's for the years 1939 to 1944 is difficult to obtain as normal trading conditions were disrupted. A large proportion of U.K. semi's production was destined for use or fabrication abroad in aid of the war effort and a sizeable quantity of imports, particularly from the U.S.A., was consumed by the U.K. industry either to produce armaments or to manufacture facilities within the U.K. to contribute to the war effort. Any estimate of this nett trade (imports-exports) in semi's would be subjective as no data is available and no estimates by other workers were found, instead it was decided to use an average figure taken from the pre-war (1922-1938) and post-war periods (1949-1976) as shown in Table 5.13.

Table 5.13 - Nett Exports of Semi's 1922-1938 and 1945-1973 Expressed as a Percentage of Semi's Production

Year	%	Year	%	Year	%	Year	%	Year	%
22	44	33	7	44	n.c.	55	11	66	10
23	14	34	3	45	4	56	17	67	9
24	11	35	5	46	15	57	19	68	10
25	4	36	5	47	10	58	22	69	10
26	6	37	2	48	9	59	12	70	13
27	6	38	1	49	15	60	12	71	15
28	5	39	n.c.	50	13	61	10	72	11
29	2	40	n.c.	51	7	62	9	73	12
30	-5	41	n.c.	52	7	63	8		
31	-12	42	n.c.	53	9	64	7		
32	2	43	n.c.	54	9	65	9		

Note: n.c. = not considered.

The overall average figure was 10% nett exports while the pre and post war averages are 6% and 11% respectively. In view of the lack of data to the contrary from published works a figure of 10% nett exports has been assumed for the years 1939 to 1944.

Columns (e) and (f) in Table 5.12 are produced in a similar manner to Table 5.11 in the previous section as was Column (g) the final consumption of copper goods.

5.6 Consumption of Fabricated Goods 1922 to 1976

Table 5.14 shows the final consumption of fabricated goods from 1922 to 1976 as described by the previous sections.

5.7 Historical Trends in U.K. and World Copper Flows

Sections 5.3, 5.4, 5.5 and 5.6 provide comprehensive tabulated time series for U.K. copper flows. These time series may be analysed to determine underlying trends in copper consumption in the U.K. Such an analysis provides relevant background information on the trends in U.K. copper flows prior to modelling the major flows. By comparing trends in U.K. and World copper flows the importance of the U.K. to the World copper industry can be measured and a subjective assessment and analysis made as to whether U.K. trends are following World trends.

The section is divided into five parts examining the following areas:

1) Trends in World and U.K. primary and secondary refined copper production and consumption.

2) Trends in semis production for alloyed, unalloyed total and individual shape groups.

3) Final consumption of fabricated goods.

4) Scrap copper flows, including cross reference to 1) above on secondary refined copper flows.

5) International trade in copper and copper alloy products.

The period considered will be 1949 to 1976 in all cases except the final consumption of fabricated goods when the years considered will be 1922 to 1976. This is due to lack of detailed statistics for pre-1949 years as discussed in Section 5.3.

Table 5.14 - Final Consumption of Fabricated Copper Goods 1922 - 1976 (tonnes x 10^3, copper content)

1922	19.3
1923	70.8
1924	100.6
1925	104.6
1926	110.3
1927	124.9
1928	129.1
1929	129.6
1930	136.0
1931	118.5
1932	100.5
1933	118.6
1934	184.6
1935	198.7
1936	223.3
1937	258.3
1938	222.0
1939	233.6
1940	391.1
1941	436.3
1942	513.1
1943	504.7
1944	395.5
1945	289.6
1946	273.8
1947	319.0
1948	318.6
1949	279.5
1950	291.0
1951	326.2
1952	339.1
1953	260.8
1954	335.8
1955	376.7
1956	344.2
1957	344.6
1958	348.4
1959	363.6
1960	422.1
1961	407.3
1962	392.9
1963	414.6
1964	477.0
1965	479.3
1966	430.8
1967	380.7
1968	395.3
1969	399.8
1970	386.0
1971	356.9
1972	379.4
1973	404.0
1974	389.3
1975	332.2
1976	354.7

This section does not describe the source of U.K. copper imports or the destination of exports. If such an analysis is identified as being necessary in later chapters it will be discussed at the appropriate point.

Care must be taken in considering the size of World copper flows as some sources quote World flows excluding Communist countries. This is due to the lack of data on flows in these countries. In this work all flows are inclusive of Communist countries unless stated otherwise.

5.7.1 Refined Copper Flows

Figure 5.9 shows U.K. production of primary and secondary copper together with total production. Figure 5.9 may be divided into two periods. In the first, 1949 to approximately 1965, a relatively stable situation apparently existed with a 4-5 year cycle on total refined production with approximately equal contributions from primary and secondary refining, despite a gradual increase in secondary refining. During the second period, 1965 to 1976, total refined production dropped from 228,000 tonnes in 1965 to 128,000 tonnes in 1976 at a rate of approximately 8 percent/annum. Primary refined production dropped dramatically in 1966 and only began a steady increase in 1971 peaking in 1972/74. A modest cyclical trend in primary refined production of 3-5 years is apparent in Figure 5.9. The growth in secondary refined production identified in the earlier period continued until 1970 after which a steep fall in production occurred to 1949 levels. Figure 5.9 also shows that the actual consumption of refined copper by the semi-manufacturers peaked in 1965 and that over the whole period there was an increase in the imports of refined copper to satisfy semi-manufacturers needs.

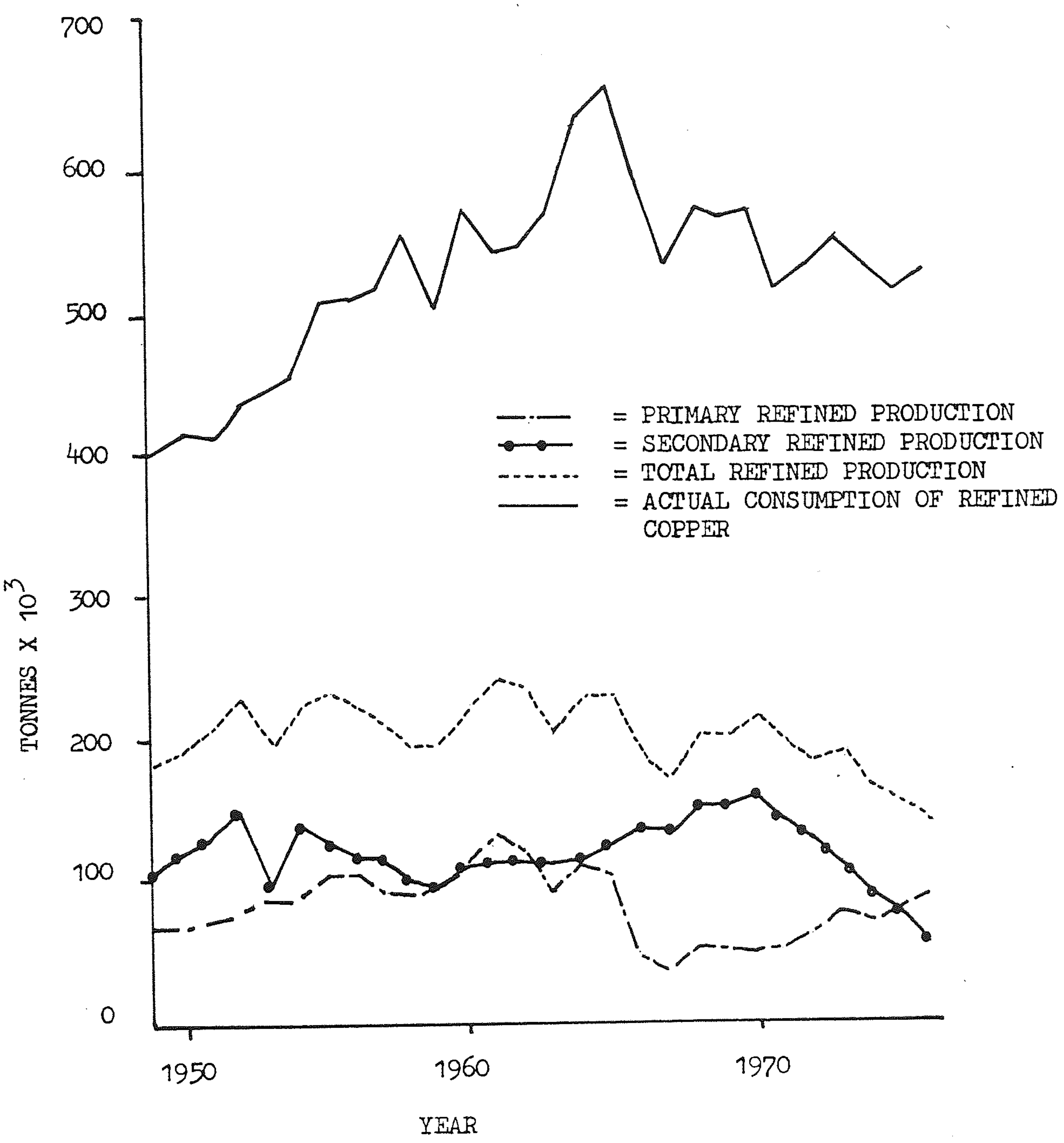


FIGURE 5.9 - UK PRIMARY, SECONDARY AND TOTAL REFINED COPPER PRODUCTION AND THE ACTUAL CONSUMPTION OF REFINED COPPER (SOURCE: TABLE 5.2)

The U.K. trends in refined copper production contrast strongly with World trends shown in Figure 5.10, where a steady increase in refined production can be identified for the whole of the period with a slowly increasing proportion of total refined production arising from secondary refining.

Figure 5.11 shows U.K. and World consumption of refined copper and differs from Figure 5.10 in that nett trade and stock changes in refined copper are taken into account. As would be expected, World consumption is nearly identical to World production (nett trade is zero) but U.K. consumption differs significantly from Figure 5.10 indicating that considerable trade in refined copper occurred. U.K. refined copper consumption reached a peak in 1965 i.e. during the previously identified stable period in U.K. refined production, and then dropped to a lower level of approximately 530,000 tonnes/annum for the period 1967 to 1976. This suggests that imports of refined copper were used to supply the semi-manufacturers during aperiod of reducing U.K. refined copper production. The reasons for this trend will be investigated in Chapter 9.

5.7.2 Semi's Production, Trade and Consumption

Semi-manufacturers and their products are the central units in copper production and consumption in the U.K. and so are discussed before other flows.

The trends in total semi's production from 1949 to 1976 are shown in Figure 5.12. Three trends are apparent:

1) A period of growth from 1949 to about 1965.
2) A period of decline from about 1965 to 1976.
3) A four to five year cyclical component.

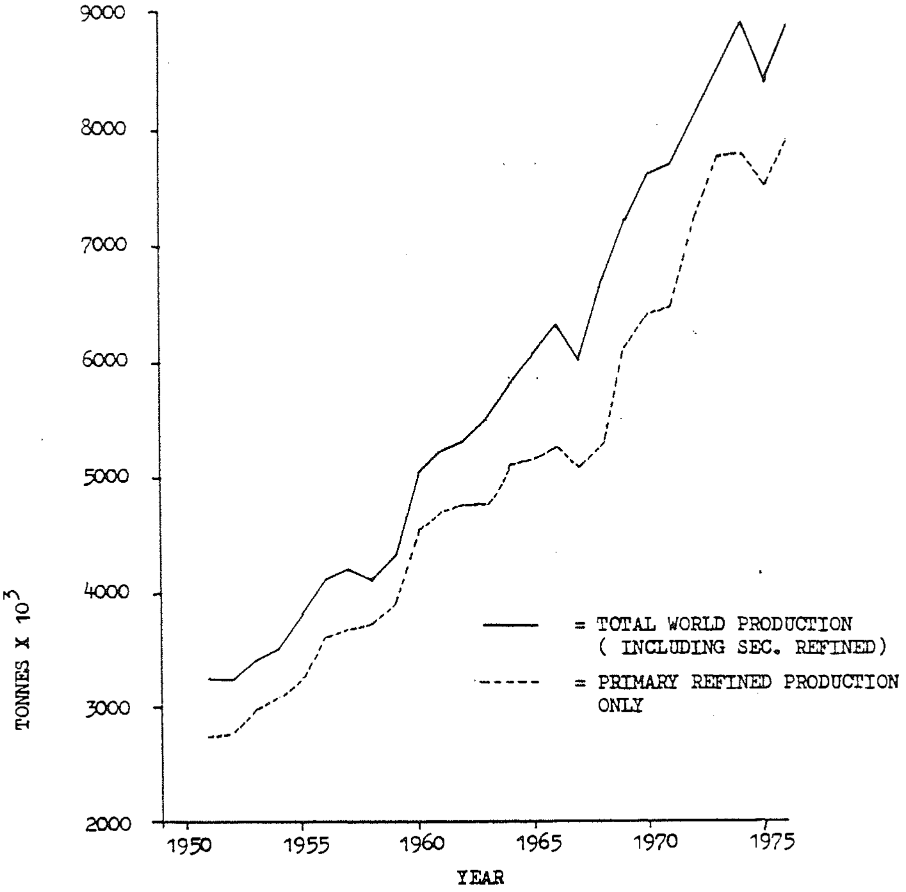


FIGURE 5.10 - WORLD PRODUCTION OF REFINED COPPER

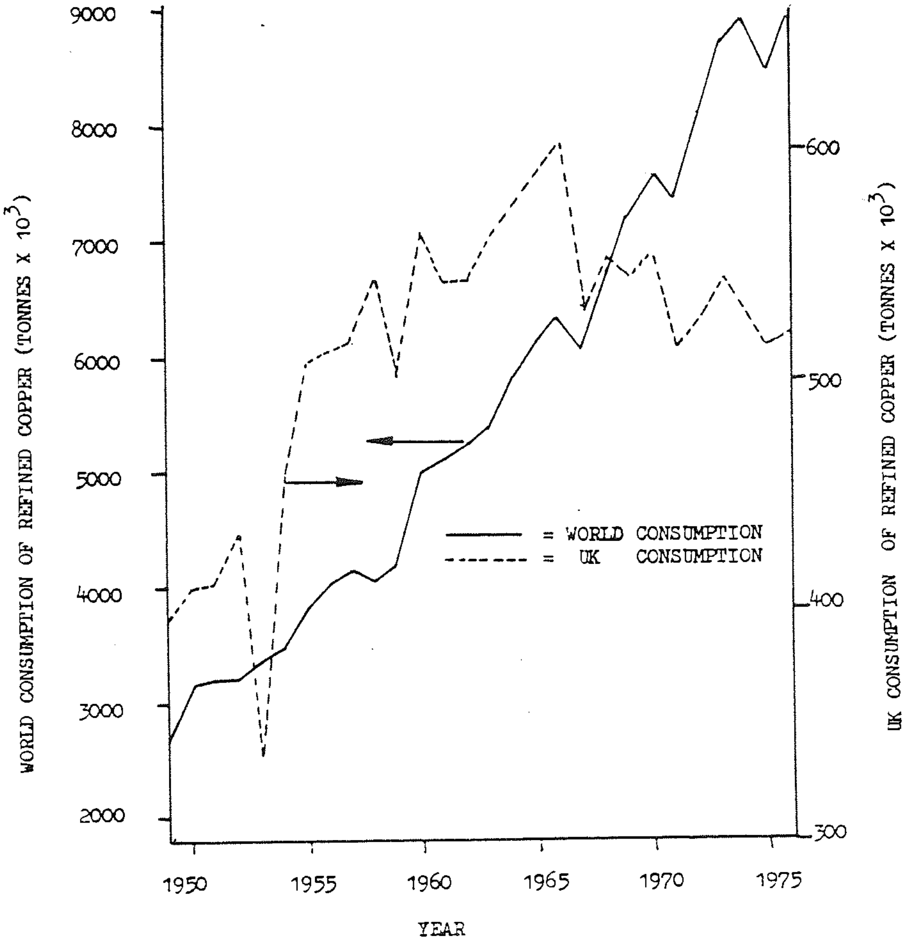


FIGURE 5.11 - UK AND WORLD CONSUMPTION OF REFINED (PRIMARY + SECONDARY) COPPER

SOURCE: WORLD: WORLD METAL STATISTICS
UK : TABLE 5.2 (actual cons)

Dividing semi's production into unalloyed and alloyed (Figure 5.12), similar trends to those above are found. In particular, the unalloyed sector shows strong growth and decline and the alloyed sector a marked cyclical trend of 4 to 5 years.

Unalloyed semi's production constitutes the largest fraction of production, averaging 62.6% of total semis production. The slowly declining importance of the more stable alloyed semis production is illustrated in Figure 5.13 where it can be seen that the percentage of total semis production from alloyed semis production has been gradually declining from a peak of 48% in 1941 to a low of 35% in 1976. The effect of this decline will be discussed later in this section.

Unalloyed and alloyed semis production may each be further broken down into shape groups, as shown in Figure 5.14 and Figure 5.15.

In the unalloyed case, the major semi produced is wire followed by tubes, sheet, strip and plate and finally rod, bar and section. All exhibit the trends listed above but to varying degrees. Wire semis show the greatest variation from these trends, possibly as a result of its use in electrical applications where major projects and changing industrial demand may have an effect. As electrical applications require a very high proportion of refined copper to satisfy strict contamination levels, demand for wire products will primarily affect refined copper consumption and as part of this demand, secondary refined copper.

The major alloyed semi produced is rod, bars and sections (Figure 5.15) followed by sheet, strip and plate, castings, tubes and finally wire. Only rod, bar and section and sheet, strip and plate show a strong cyclical component. In contrast to unalloyed semis, alloyed semis production can use a high proportion of scrap. This results in a situation where scrap demand is a function of a relatively stable, but cyclical alloy semis production level and the demand for secondary refined copper,

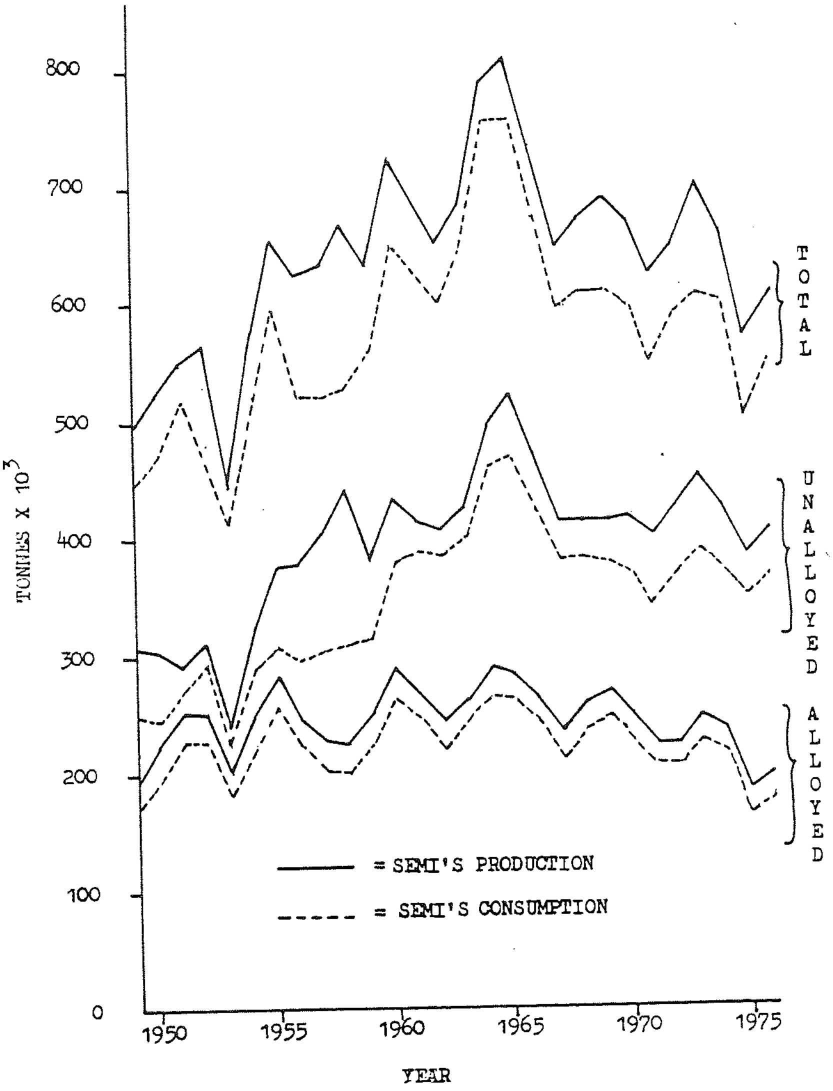


FIGURE 5.12 - PRODUCTION AND CONSUMPTION OF SEMI'S, 1949-1976

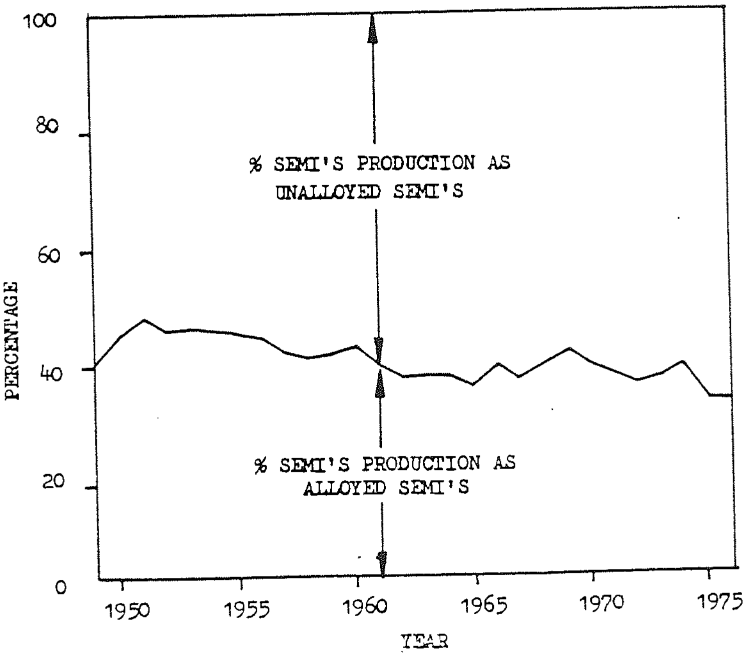


FIGURE 5.13 - PERCENTAGE OF TOTAL SEMI'S PRODUCTION AS UNALLOYED AND ALLOYED SEMI'S

SOURCE: CALCULATED FROM TABLE 5.5

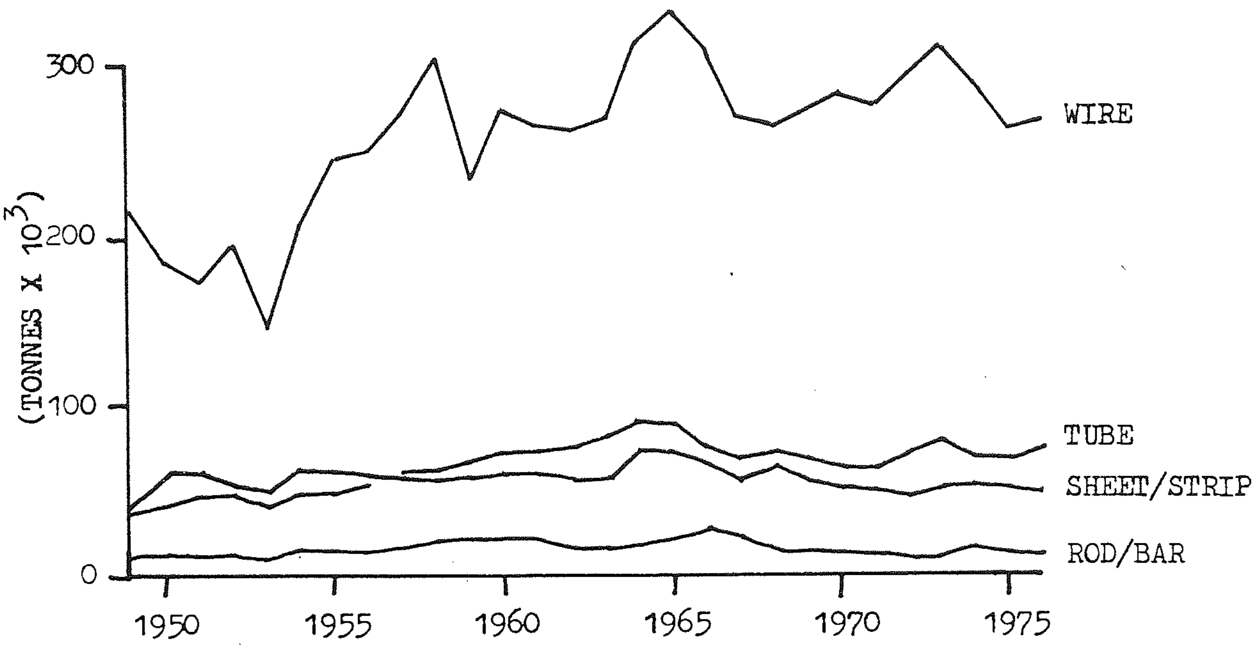


FIGURE 5.14 - UNALLOYED SEMIS PRODUCTION BY SHAPE GROUP

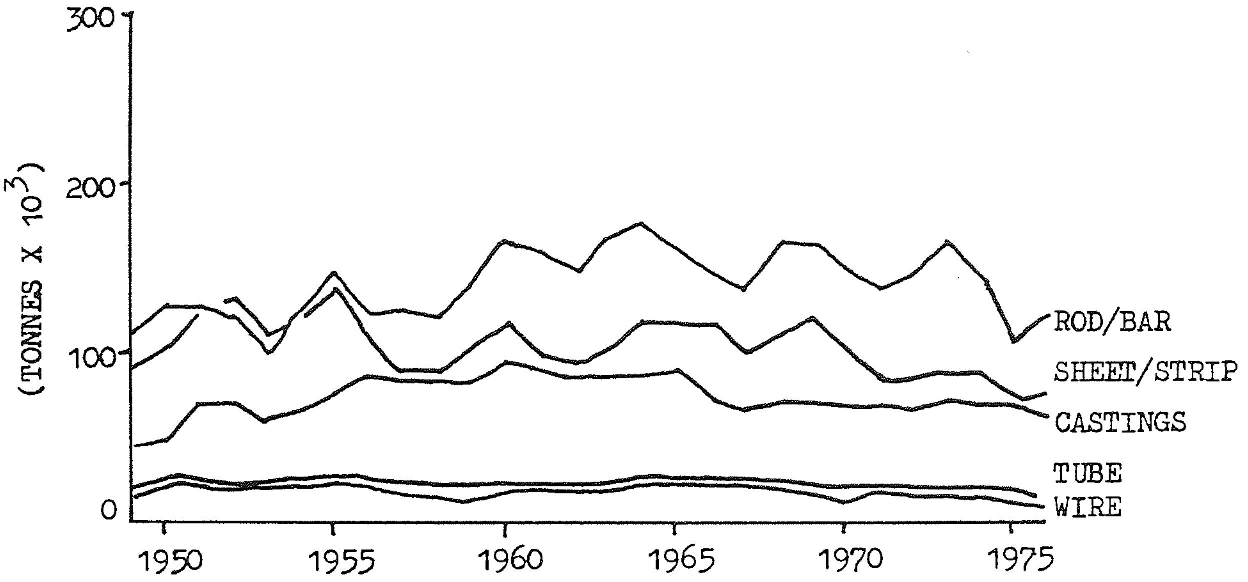


FIGURE 5.15 - ALLOYED SEMIS PRODUCTION BY SHAPE GROUP

itself a function of unalloyed wire demand. As the secondary refined copper industry is limited by plant considerations, it is likely that the more volatile unalloyed wire demand will be satisfied by imports of refined copper. This aspect of UK copper flows will be examined in more detail in Chapter 7, but reference to Figure 5.14 and Table 5.2 shows a general correlation between the two flows.

Figure 5.13 showed a decline in the relative importance of alloyed semis production compared to unalloyed semis production. If, as expected, alloyed semis production is a major market for copper scrap then the continuation of the trend identified in Figure 5.13 may have significant long-term effects upon supply/demand relationships for copper scrap in the U.K. This will be discussed in more detail in Chapter 9.

The trends identified in semis production i.e. growth from 1946-1965 and decline from 1966-1976 are best explained by using unalloyed tube production as an example. Over the period 1949 to roughly 1965 two factors contributed to a growing demand for copper tube. The first was a growing economy, still recovering from the Second World War and the second was the growing number of houses having central heating installed. Over the remaining period to 1976, periods of relatively high price of copper (Chapter 6) meant a reduction in demand partially offset by the adoption of thinner walled tubing. The trends in the production of other semis may be explained in a similar fashion, but with other dependent factors.

The cyclical component in the production of alloyed semis demonstrates the ability of the alloyed semi-manufacturers to respond quickly to changes in industrial demand, which generally follows a five year cycle.

Figure 5.12 also shows that the UK has been a net exporter of both unalloyed and alloyed semis over the entire period considered averaging 8% of total semis production and 10% and 1% of unalloyed and alloyed semis production respectively. The fairly constant nature of international trade in semis suggests that the trends observed in semis production also apply to semis consumption.

5.7.3 The Final Consumption of Copper Goods

The final consumption of copper in goods within the UK for the period 1922 to 1976 is shown in Figure 5.16. No comparable World data on the final consumption of copper in goods is available.

Figure 5.16 exhibits four distinct trends. They are, in chronological order:-

1) A period of high growth from 1922 to 1938 averaging 20%/annum.

2) A sharp peak in consumption over the years 1939 to 1945 as copper contributed to the war effort.

3) A period of lower growth (compared to the 1922 - 1938 period) between 1946 and 1964 of 5%/annum.

4) A period of decreasing consumption (1964 to 1976) at a rate of approximately 3%/annum.

Over the total period, 1922 to 1976, copper consumption rose from 25,000 tonnes/annum to a peak of 513,000 tonnes/annum in 1942. A post-war peak of 497,000 tonnes in 1965 was followed by a drop in consumption to a 1976 level of 355,000 tonnes/annum.

It is not clear from Figure 5.16 whether the growth and later, decline patterns, are linear, exponential or logistic in format. Evidence for all three patterns could be put forward, but the methodology used to calculate the final consumption of copper goods involves assumptions which may adversely influence, in particular, the figures for pre-war years. This, in turn, will affect the type and accuracy of growth (or decline) patterns fitted.

FIGURE 5.16 - FINAL CONSUMPTION OF COPPER IN GOODS, 1922-1976

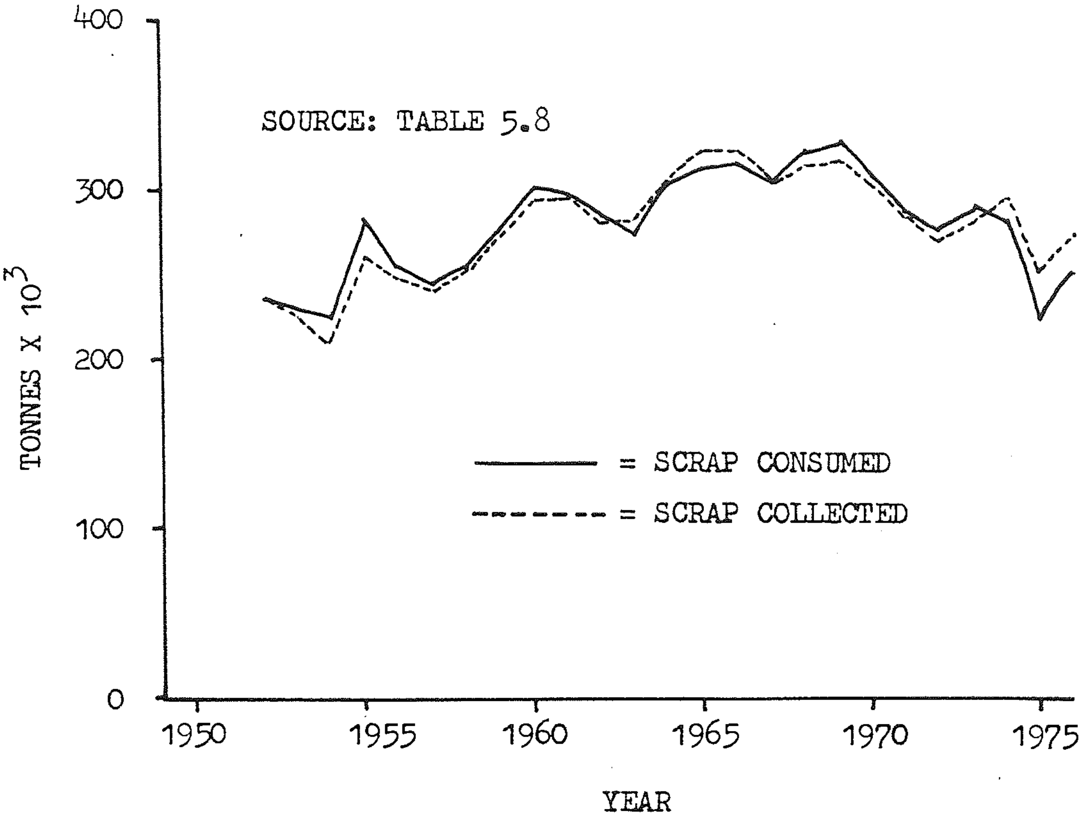
SOURCE: TABLE 5.14

Figure 5.16 does, however, indicate that a gradual decline in copper consumption in the U.K. is likely to continue into the near future. The effect of this decline, and of the other historic trends identified above, upon scrap supply will be discussed in Chapter 9.

5.7.4 Scrap Flows

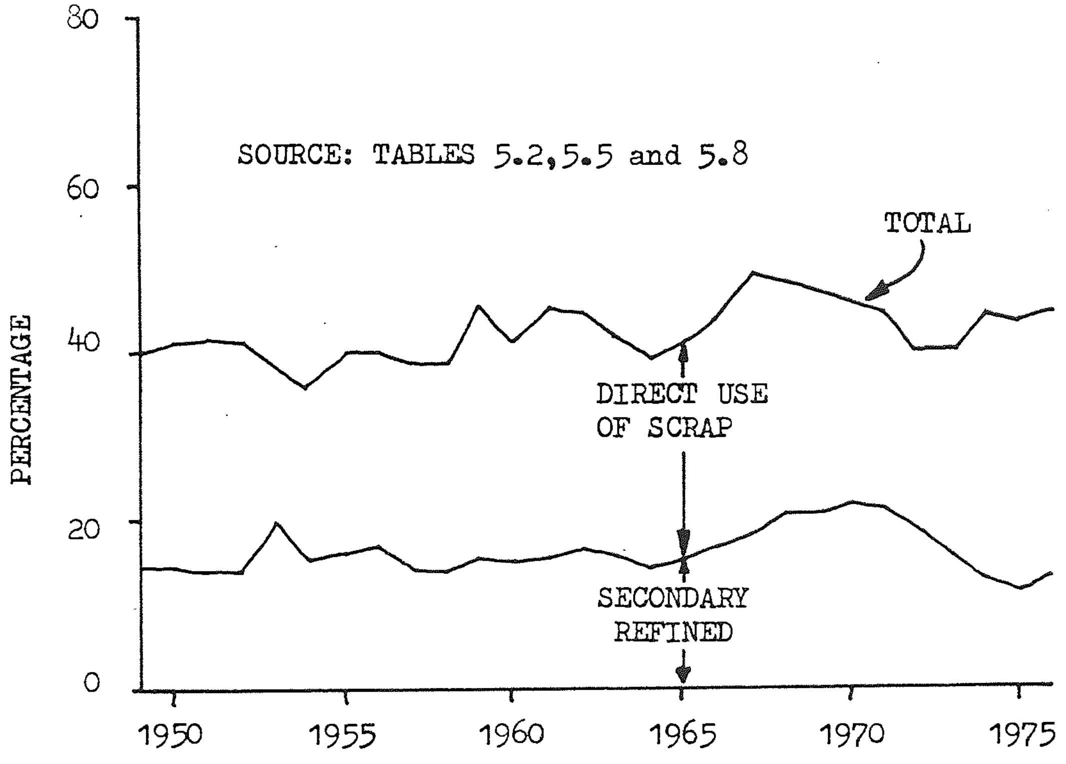
Scrap flows are generally categorised either by source or by destination as discussed in Chapter 2. Source scrap includes new and old scrap while destination scrap includes the direct use of scrap and the consumption of scrap by secondary refineries. Each classification will be considered separately after examination of the trends in total scrap consumption.

Figure 5.17 shows that the consumption and collection of scrap in the U.K. has shown wide fluctuations since 1945 although, as expected, the trends noticed earlier (Section 5.7.2) in the production of semis are evident i.e. growth until circa 1965 followed by a period of decline to the present. The dependence of the alloy semi-manufacturers upon scrap as a feedstock (discussed in Section 4.2.9) is seen in the strong four to five year cyclical component in Figure 5.17 which is similar to and in phase with the cyclical component of alloyed semis production shown in Figure 5.12. Similarly, the sedate trend in the percentage of semis produced from total scrap consumed as seen in Figure 5.18 shows the contribution of secondary refined and direct-use of scrap to semis production. The trend in secondary refined production has already been discussed (Section 5.7.1) and the direct use of scrap has averaged 26% of semis production over the period in question although the declining importance of the secondary refiners contribution has meant that the an increase in recent years to 31%.



SOURCE: TABLE 5.8

FIGURE 5.17 - TOTAL SCRAP COLLECTED AND CONSUMED, 1949-1976



SOURCE: TABLES 5.2, 5.5 and 5.8

FIGURE 5.18 - PERCENTAGE OF SEMIS PRODUCTION FROM TOTAL, SECONDARY REFINED AND DIRECT USE OF SCRAP.

Figure 5.19 shows that, as would be expected from the statistical analysis employed, the contribution of new scrap varies only with the trade in semis and changes in the production of individual shape groups, while old scrap varies more. While the assumptions used in calculating the contribution of old scrap may produce inaccurate results, the results do show that the use of scrap is a major factor in semis production and that the market can respond quickly to changes in demand for old scrap.

It has often been argued (for example, see (88) that the UK does not use its scrap efficiently and in fact suffers from a surplus which is exported whenever possible. Reference to Table 5.8 shows that, in fact, the net trade in scrap, as far as the UK is concerned, is small except for 1954 and 1955 and, more recently, 1972. In these years the trade in copper scrap resulted in a net import of scrap. Over the last three years considered (1974, 1975, 1976) however, net trade was in the opposite direction i.e. a net export of scrap.

5.7.5 Trends in International Trade in Copper and Copper Bearing Goods

In section 5.3 international trade (in this section referred to as 'trade') in copper goods was included in the statistical description of the copper flows. Table 5.15 lists those flows for which published statistics were found. Reference should also be made to Figure 5.7 which shows the relative size of UK copper flows for 1976.

Table 5.15 - U.K. Flows Involving International Copper Trade

Form of Copper	Flow
Refined	Imports of ore/blister Trade in refined copper
Semi-manufactures	Trade in unalloyed semis Trade in alloyed semis
Ingots	Trade in alloy ingots
Fabricated goods	Trade in fabricated goods
Scrap	Trade in unalloyed scrap Trade in alloyed scrap

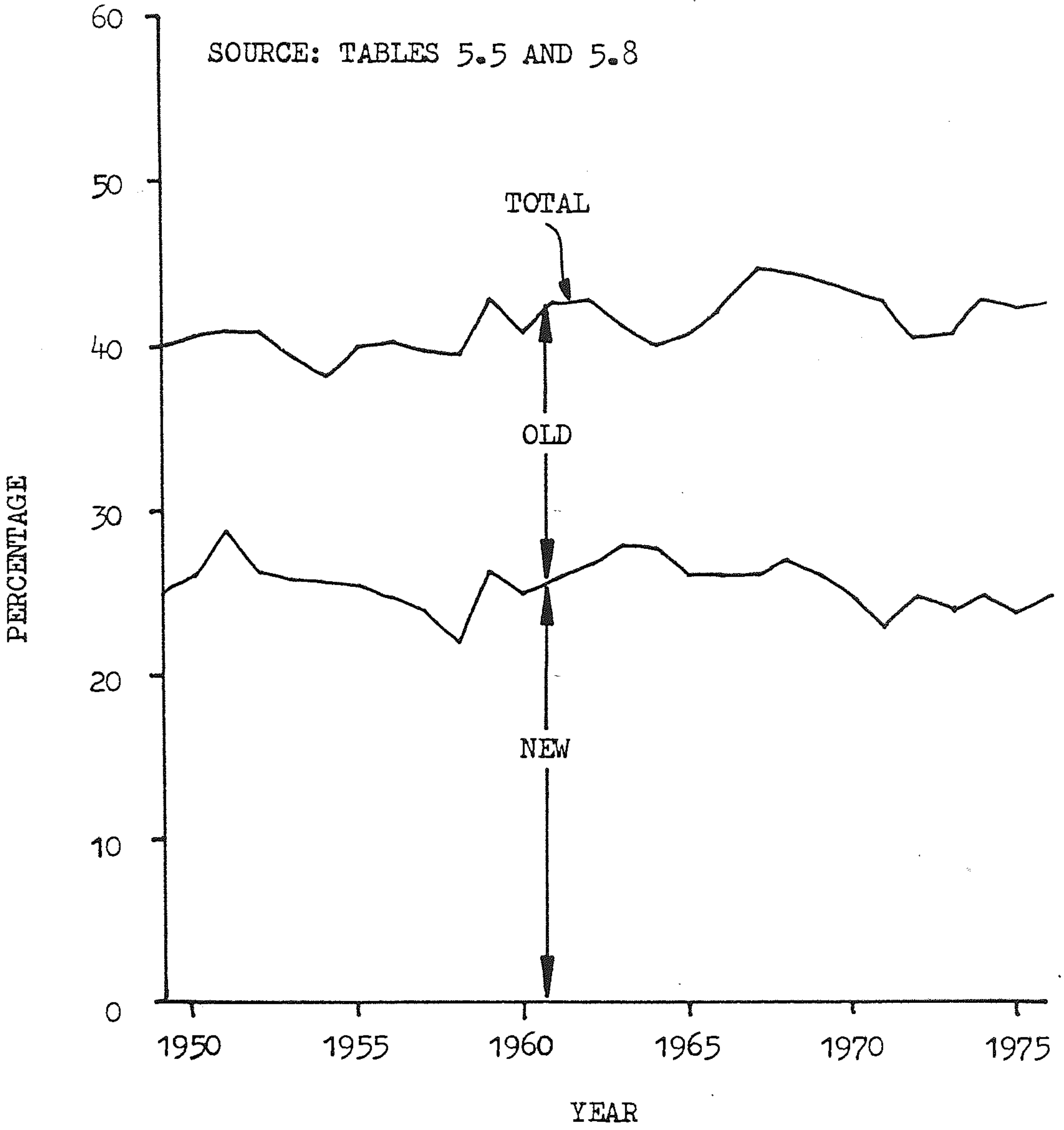


FIGURE 5.19 - PERCENTAGE OF SEMIS PRODUCTION FROM TOTAL, NEW AND OLD SCRAP CONSUMED

Detail in the copper content of trade in copper alloy flows is scarce and instead the value of this trade, which is more readily available, has been examined. The value of copper trade is found in UK Mineral Statistics (80) and is reproduced in Table 5.16.

The convention used in Table 5.16 is that a negative figure indicates a surplus of exports over imports i.e. a net loss of copper scrap to the U.K., a situation which benefits the UK Balance of Payments.

Figure 5.7 and Table 5.16 show that trade is dominated by imports of refined copper and trade in semis. Other significant trade flows include imports of blister for primary refined production, exports of alloy ingots and sulphate and trade in scrap. It should be remembered that both ingot and sulphate production rely heavily upon the use of scrap. This means that imports are dominated by refined copper in metal and blister, a proportion of which is then exported as semis; while scrap, in the form of ingots and sulphate are major export earners.

The most readily identified method to reduce the measured overall UK Balance of Payments given in Table 5.16 for 1974 as £273 million, is to reduce imports of refined copper costing. £351 million. Taking an average scrap price, calculated from Table 5.16, of £700/tonne, then in 1974 a collected scrap figure of 168,000 tonnes (Table 5.8) saved the U.K. £118 million in imports of refined copper. Virgin refined copper will always be necessary to supplement copper lost during or after end-use and to dilute contaminant levels. In 1974 copper scrap supplied 45% of semis production and an increase in this figure may be possible with subsequent refined copper import savings. This will be discussed in more detail in Chapter 10.

Table 5.16 - Volume and Value of U.K. Trade in Copper, 1974 (80)

Flow	Import (b)		Exports (b)		Nett trade (b)	
	tonnesx10^3	£x10^3	tonnesx10^3	£x10^3	tonnesx10^3	£x10^3
Ores matte and concentrates	0.0	24	0.7	1119	-0.7	-1095
Scrap	26.1	17631	30.0	21446	-3.9	-3815
Blister	72.1	67067	n.a.	n.a.	+72.1	+67067
Refined	386.4	345366	35.0	30922	+351.4	+314444
Alloy ingots	0.2	457	35.7	25409	-35.5	-24952
Worked metal (a)	42.3	50353	111.9	125105	-69.6	-74752
Sulphate	n.a.	n.a.	12.7	3792	-12.7	-3792
TOTAL	527.1	480898	226.0	207793	+301.1	+273105

(a) Worked metal = semis
(b) Gross, no attempt has been made to estimate copper content
(c) Negative sign indicates nett exports of copper.
n.a Not available.

5.8 Summary to Chapter 5

The sources of published statistics on UK copper flows were examined. World Metal Statistics was found to be the most consistent source of data for copper flows after 1949. Alternative sources were identified for wartime and pre-war years from 1922.

The statistical sources were used to comprehensively describe UK copper flows from 1949 to 1976. Less detailed statistics orientated towards the final consumption of copper goods (to enable scrap supply patterns to be analysed in Chapter 8), were also developed.

The published statistics on copper flows were found to be lacking in a detail sufficient to close the loop of copper production, consumption and recycling. By adopting specific assumptions the loop was closed but possibly at the loss of detailed accuracy, particularly with respect to flows to and from the fabricators. The published figure on the direct use of scrap, a major copper scrap flow, was found to be a calculated figure obtained from other copper flows and of questionable accuracy. These inaccuracies, however, are more than compensated for by the usefulness of the statistical analysis which allows either a snap-shot to be taken of all UK copper flows in any one year or the examination of a trend in any flow over a number of years. In the case of consumption of fabricated goods a time series has been developed from 1922 to 1976; no other such time series for the UK is known to exist.

Copper flows for 1976, the last year to be analysed, were shown in diagrammatic form. Refined copper flows, particularly from imported refined copper, dominated UK copper flows with copper scrap (evenly split between secondary refined, direct use and ingot forms) supplying approximately 45% of semis production.

In the final part of Chapter 5, trends in specific copper flows were examined. UK refined copper production was found to peak in 1961 after which primary refined production fell to a low level and secondary refined production continued to rise until 1970, after which it dropped dramatically. This was found to be contrary to World trends, which showed a steady increase in all aspects of refined production and consumption.

One other trend was identified which may adversely affect the UK scrap market. While total semis production peaked in 1964, the overall contribution of alloyed semis, a major market for copper scrap, fell. If this is combined with a possible decline in the production of unalloyed wire (due to substitution for copper), the major market for secondary refined copper, then the future of the UK scrap market would appear grim. Despite these indicators, the percentage of semis production from all scrap forms remained stable at around 40% over the period considered and it must be concluded that the future of the UK copper scrap industry is heavily dependent upon unalloyed copper wire production.

International trade in copper was found to cost the UK £273 million in 1974, mainly due to imports of refined copper valued at £314M. Any increase in UK copper recycling to the semi-manufacturers will reduce this high cost to the UK Balance of Payments.

In the following chapters, the major UK copper flows developed in this chapter will be modelled so that future patterns of copper consumption and their cost to the UK can be examined. The effects of policy decisions by corporate planners, or by the government, may then be examined and an economic assessment made of their impact.

CHAPTER 6 : THE ECONOMIC THEORY OF MODELLING AND COPPER PRICES

6.1 Introduction

The aim of this Chapter is to investigate the techniques available to model the major flows in the copper industry, and in particular those methods suitable for modelling the demand for copper and the supply and demand for secondary copper. Following this analysis models will be formulated to explain quantitatively any correlation between these factors so that trends and fluctuations in the copper market can be identified and the effect of various policy decisions investigated.

In practical terms a methodology to comprehensively examine all the possible factors affecting the copper market is not possible due to limitations in the quantity and quality of data and information available and the time available for study. In particular, the lack of empirical work on modelling UK copper flows means that a model framework had to be developed from basic principles and from published works (mostly from the United States) so the modelling approach adopted was, to the authors knowledge, new to the UK copper industry.

In the first section of this chapter the types of modelling techniques available are discussed and a modelling technique selected. A discussion and literature review of the factors affecting copper prices is then given prior to modelling UK copper semis demand in Chapter 7 and the supply and demand for copper scrap in Chapters 8 and 9.

6.2 Selection of Modelling Technique

6.2.1 Available Modelling Techniques

There are three basic approaches to modelling although specific methods may not automatically be classifiable as one of these - most models will, in fact, be found to include a combination of two or three of these approaches.

1. Intuitive Methods

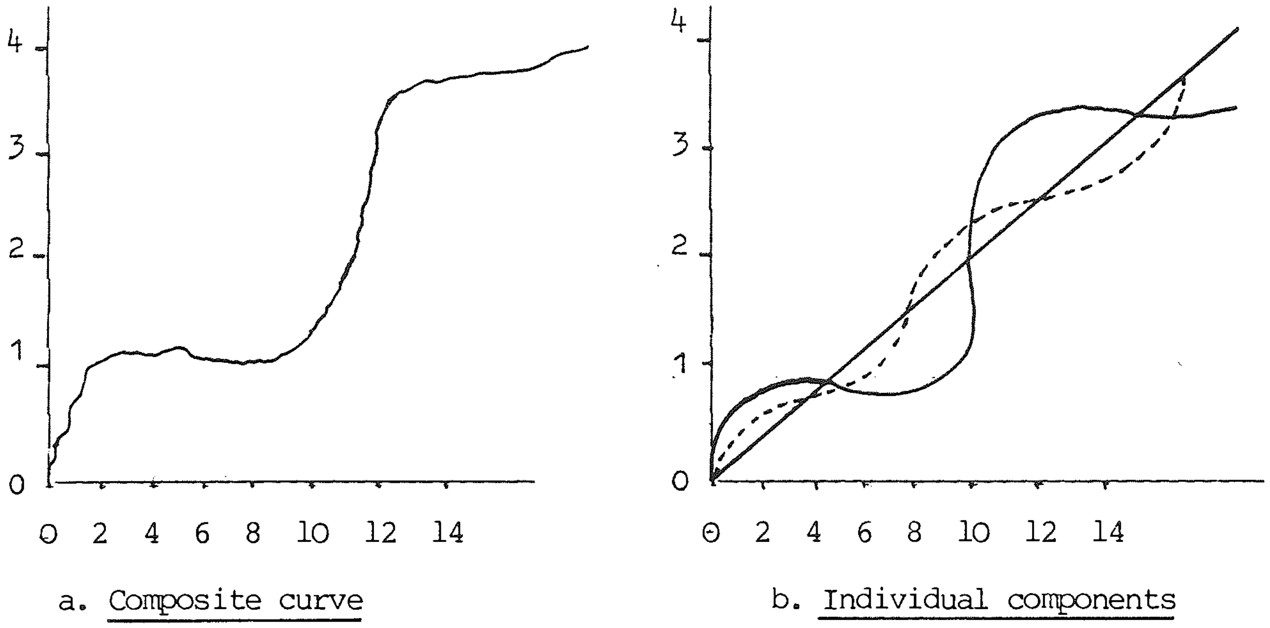
These methods are sometimes referred to as qualitative or judgemental methods and are based essentially on an individual or groups feeling for a situation and may or may not take the past into account. Human judgement is used to turn qualitative estimates into quantitative ones and these methods are mainly used when quantitative data is in short supply as in the case of the introduction of a new product or when longterm forecasts involving, for example, technological change, are required.

In order to remove personal bias various formal techniques have been derived, e.g. Delphi and an excellent review is given by Firth (111) who concludes that while intuitive methods are subject to a fairly high degree of error their generality can provide valuable information.

2. Time-Series Methods

Time series methods establish patterns and trends in a historical series of data and then extrapolate these patterns and trends into the future. The model is then based upon the assumption that the pattern will recur over time ; an assumption which is more likely to be true in the short term and for relatively stable data. For this reason, time series analysis is used mostly in short term forecasting and where a relatively stable variable is being investigated. Firth (111) considers time series methods to be not so applicable in longer term decision areas or situations in which little data is available, a view supported by Wood and Fildes (112) and Chambers (113).

The methods used are normally of a mathematical or statistical nature and often begin with a basic model relating the dependent variable to a single independent variable. When this model is thoroughly understood it may then be made progressively more complex by the addition of extra terms and relationships. For example the curve shown in Figure 6.1(a) may be composed of a linear growth trend, a ten year cyclical component and a four year cyclical component shown in Figure 6.1(b).



a. Composite curve b. Individual components

Figure 6.1 - Time Series Components of a Composite Curve

3. Causal Methods

These methods are based on attempts to forecast effects using knowledge of the cause of these effects by utilising historical data and statistical theory and techniques. The form of the final model varies but generally the item being forecast (the dependent variable) is mathematically related to a number of independent variables which have some determining influence upon the dependent variable. For example, sales of an industrial product may be influenced by advertising expenditure, number of salesmen, price and perhaps the level of industrial activity. Application of statistical theory to the data available would show that all these factors were relevant with the exception of the latter and sales may be described for example in the form:-

$\text{Sales} = aA + bS + cP$ where A = advertising expenditure

S = Number of salesmen

P = price

a,b,c = coefficients applied to the factors

Accurate forecasts of A, S and P are necessary before meaningful forecasts of the dependent variables, sales, can be made.

Causal models differ from intuitive and time series models in that continuous data is not necessary to provide reliable quantitative results.

A survey of different modelling techniques by Chambers (113) showed that causal models are the best for predicting turning points (i.e. significant changes in growth) and preparing long-term forecasts. However, they can also be the most costly to construct and operate, and often require considerable effort in data collection. Firth (111) as well as Chambers (113) note that causal models can be quite sophisticated, and managers and decision makers may require special training and/or extensive experience to interpret the results obtained.

6.2.2 Factors Affecting Selection of Modelling Techniques

While accuracy is a primary objective of any forecasting technique other factors must also be considered in selecting a suitable method. The more important factors are:-

1. Accuracy

The need for accuracy depends upon the decision to be derived from the model. A higher degree of accuracy may be necessary for cases involving borderline decisions e.g. between profit and loss than for cases where accuracy may be balanced by another property of the model, such as speed or a more distant time horizon. Causal models have been found (111,112,113) to give the greatest accuracy in medium and long term forecasts.

2. Time Horizon

This is the time over which the forecast will be statistically "accurate". Time horizons may be divided into approximate lengths and while not definitive typical time horizons are given in Table 6.1 and will be used during the rest of this work. Immediate and short-term forecasts are normally used for operating control for example allocation of raw materials to different products. Short and medium term forecasts cover areas where major policy variables can be embarked upon while longer term situations allow major strategic alterations to be made.

Table 6.1 - Approximate Duration of Various Time-Horizons (111)

Time Horizon	Approximate time from present (years)
Immediate	0 - 0.25
Short-term	0.1 - 0.5
Medium-term	0.25 - 2.0
Long-term	2 - 10
Very long term	> 10

Generally, the longer the time horizon the less accurate the forecast. Extrapolation of past data (i.e. time series analysis) is probably the best guide for the short-term while causal models are often most appropriate for medium/long term models. For very long terms intuitive models should be considered.

3. Speed and Regularity

In some cases forecasts need to be frequently updated at small, regular intervals such as in process plant control systems, while in other cases only a single forecast per year is necessary. Often a balance between speed and accuracy has to be made.

An important property of a model is the ability to differentiate between true turning points and short-term random effects at an early stage.

Intuitive models can be difficult and laborious to construct while both time-series and causal models can be easily updated and, if necessary, modified as fresh data becomes available.

4. Detail

The detail of a model refers to the degree of disaggregation possible; for example whether total sales or sales by individual products may be modelled. The detail of a forecast is normally governed by the detail of the input data and so little control may be exercised over this factor.

5. Relevence

A forecast must be relevent to the decision situation and not just a sophisticated mathematical model which produces an unreasonable number of uninterpretable forecasts.

6. Data Requirements

The statistical requirements of data gathering, screening, interaction and accuracy are a particularly deciding factor in the value of a forecasting model. The theory of data requirements is adequately covered in literature (111,112,114) and only problems associated with the selected modelling technique will be discussed when relevant.

6.2.3 Selection of Modelling Technique

In the UK some research has been carried out into forecasting practices by the British Institute of Management (115), Jones and Morrell (116) and Strong (117). However, the most detailed survey was that conducted by Turner (118) in 1968 and 1969. Turners findings were largely the same as those found in similar US surveys and specifically that:-

a) Forecasting is an important aspect of a companys operation.

b) Larger firms adopt more sophisticated techniques.

c) A fairly rapid growth in forecasting was occurring.

d) Simple time-series techniques were the most popular.

e) Causal models (and in particular econometric models (Section 6.2.4)) were considered to be beyond the scope of most companies. Reasons given included cost, time for data collection, computing and model formulation and, in particular, time for forecasting exogenous independent variables.

Turner's findings largely agree with those found for the UK copper industry, where the steady growth in most flows identified in Chapter 5 lead to the adoption of simple time-series methods. The turning point identified over the period 1965-1970 and unidentified by time-series methods means that other modelling methods have to be adopted. Additionally, time series methods are unsuitable for investigating the effects of policy decisions as they rely upon the continuation of historic trends and cycles into the future and cannot easily include the effects of policy decisions. Therefore, this implies that the model must be either intuitive or causal but not time-series as the aim of this work is to provide a framework within which the effects of various policy decisions can be investigated.

The time-horizon for the model is, in the case of copper, governed by the time interval between data points. It has already been noted in Chapter 5 that the only consistent sources of data over the necessary period is annual and for this reason the time-horizon must be medium (a quarter to two years), long (two to ten years) or very long (greater than ten years) term (see Table 6.1).

Intuitive methods are particularly suitable for longer time horizons and are able to identify major turning points, but this is outweighed by the greater accuracy of causal models combined with an ability to quantify the effects of policy decisions. However, this does not mean that intuitive methods will not be incorporated into the final causal model whose formulation may rely upon the interpretation of qualitative statements and views expressed in published articles together with the authors own views.

Having eliminated both intuitive and time-series methods, the ability of a causal model to suit the needs of this project must be examined. Causal models usually have the greatest accuracy and the time horizon is also usually acceptable at one to ten yeas. But perhaps most importantly the basis of a causal model makes it particularly suitable as the underlying reasons for trends and turning points need to be understood before the model can be accurate. This means that policy decisions can be investigated in a quantitative manner. The problem of relevance must not be ignored so that a model which uses unavailable or uncertain future values of independent variables must be avoided. It is appreciated that causal methods are difficult to construct and that their interpretation is difficult, but no other modelling technique appears to provide the flexibility and accuracy of this type of model.

6.2.4 Types of Causal Model

Various types of causal models have been developed, differing in the degree of sophistication and purpose of use. Most causal models are constructed to identify economic and business factors affecting a particular aspect of a macro or micro economic system and are normally developed and constructed by economists. This group of causal models are termed econometric models.

Of necessity, the econometrics utilised in this study may be considered naive, but the primary objective of achieving a useful forecast for the copper industries was considered more important than an academically biased treatise on advanced econometrics.

Although the term econometrics is often applied as a general description of quantitative economic models, econometric models strictly refer to the setting up and solution of a series of simultaneous equations which reflect the interdependency of many independent and dependent economic variables. As the econometric model is the basis of a series of other modelling techniques, it will be discussed in some detail.

Econometric models basically consist of four equations (111,112) although in practice many more are present.

$$D = f\,(D{-}1,\ P,\ P^c,\ A,\ T)$$

$$Q = g\,(Q{-}1,\ P{-}\theta,\ N,\ Z)$$

$$P = h\,(P{-}1,\ D,\ I)$$

$$I = I{-}1 + Q - D$$

where D = demand
Q = supply
P = price
P^c = price of substitutes
$P{-}\theta$ = prices with lag distribution
I = Inventories or stocks
A = Activity level
T = Technical factors
N = Natural factors
Z = Policy variable.

In the equations, demand is explained as being dependent upon prices, economic activity, prices of substitutes and possible technical influences. Accordingly, supply would depend on prices as well as natural factors and lagged price. Prices are explained by demand and stock levels and the model is closed using the market clearing identity which relates current stock levels to lagged stock levels, supply and demand.

The variables may be classified as endogenous variables or targets (D, Q, I and P); lagged endogenous variables (D-1, Q-1, I-1 and P-1); and exogenous variables or variables determined outside the system being modelled (P^c, A, T and Z). The necessary condition for an equation to be exactly identified is that the number of exogenous and endogenous variables absent from that equation must equal the number of endogenous variables in the system minus one. Providing that all equations in a model may be identified in this way, then the relevant coefficients may be found by the method of indirect least squares.

The formulation of simultaneous equation econometric models is a complex and costly operation for all but the largest firms and organisations. At present most econometric work is carried out by government economists who build models of the economy involving many hundreds of equations to produce econometric forecasts of major economic indices.

It must be concluded that the complexity of econometric models, together with the large amount and unavailability of necessary data make such models impractical, for a project of this nature. This is confirmed by the lack of such causal models for the copper industry except that some modelling has been carried out in the very special US situation which is unique in being almost completely self determining. The US models failed to model the European copper markets and no other works specific to causal modelling of the UK copper industry has been found.

The alternatives to a complete econometric model is to attempt to establish individual equations of the complete econometric model using available data and regression analysis techniques. It is appreciated that such models would have to be used with care and would rely heavily upon the use of exogenous variables, but it is felt that providing the equations used adequately explained the market forces involved then the errors introduced by not closing the model and accurately assessing coefficient values would be minimal.

6.2.5 Statistical Tests for Causal Models

The statistical tests to be satisfied by a causal model formulated by regression analysis are described in Appendix 1 and summarised below.

Table 6.2 - Expected Value of Statistical Tests used in Regression Analysis

Statistical Test	Symbol	Expected value
1. Standard error	SE	As low as possible
2. t-test	t	> ± 2 (assumes > 15 observations)
3. Coefficient of correlation	r	-1 to 0 to +1 (nearer ± 1 the better)
4. Coefficient of determination	r^2	0 to +1 (nearer +1 the better)
5. F-statistic	F	>6 (assumes >6 observations)
6. Durbin-Watson Test	D-W	0 to 4, as near to 2 as possible.

6.2.6 Summary of Section 6.2

A relatively simple causal model consisting of individual equations will be constructed, but without producing mutually exclusive solutions. Regression analysis will be employed relating to available literature on data and economic factors such as market forces; supply and demand; prices and stock levels.

6.3 Copper Pricing

The interrelated nature of the copper industry raises problems in the order in which the aspects of the industry should be discussed. For example, in a true market economy, the price of a commodity reflects the balance between supply and demand and is the central component in any econometric analysis. This is particularly true in the case of copper and the interaction between primary and secondary copper markets.

In the remainder of this Chapter and Chapters 7, 8 and 9 an a priori analysis attempts to present the qualitative basis of the models to be developed in such a way that the major variables are discussed in a logical order.

In this section the pricing mechanisms for copper will be discussed and a suitable deflated copper price selected owing to the importance, explained above, of copper prices to the UK copper industry.

6.3.1 Pricing Mechanisms for Unwrought Refined Copper

There are three main pricing systems for unwrought refined copper, they are the US producers price, the New York Commodity Exchange price (COMEX) and the London Metal Exchange price (LME) (89) (93).

The importance of the US producers price arises from the size of US copper production and consumption. The high oligopolistic industrial structure and partial insulation of the US copper industry due to domestic mine production of copper have combined to produce in the US a pricing system where the producers price is regulated by the major integrated copper producers who also are some of the worlds major copper producers. That is, prices are set unilaterally by the major US producers rather than by an auction system as exists at the LME or COMEX. For this reason, the US producers price is relatively constant and static over time. In periods of excess demand the producers ration supplies rather than raise prices. Similarly, at times of over supply the producers stock pile. The fact that consumers will pay either high or low prices reflects an important aspect of the copper industry in that long run certainty of supply is preferred over short term benefits.

The COMEX price closely follows LME prices and will not be discussed further.

The LME price is a free market price determined by a twice daily auction system. Thee are two prices quoted on the LME, the cash price and futures price. Futures price is the price quoted for delivery on any date in the next three months and is normally higher than the cash price for immediate delivery. Futures trading provides the opportunity for hedging, the purpose of which is to provide protection against uncontrollable fluctuations in price.

The importance of the LME exceeds its role as a market place for copper. Only a fraction of total world trade in refined copper passes through the LME (10% according to the Bankers Trust Company (89) and 14% of UK refined copper imports (96)), but the exchange acts as an equilibrating mechanism for the world copper industry. Typically refiners dispose of production in excess of commitments through merchants operating on the LME. Similarly, semi-manufacturers acquire amounts of copper in excess of scheduled deliveries through the LME. The LME therefore handles what are really the excess supply and demand of the world copper industry as well as setting price levels as described above. LME and US producer prices for unwrought refined copper are presented in Figure 6.2 for the period 1949 to 1976. This data is included in Appendix 2 where all relevant data to this and later chapters will be listed. Figure 6.2 suggests that US producers prices are generally parallel to those on the LME although

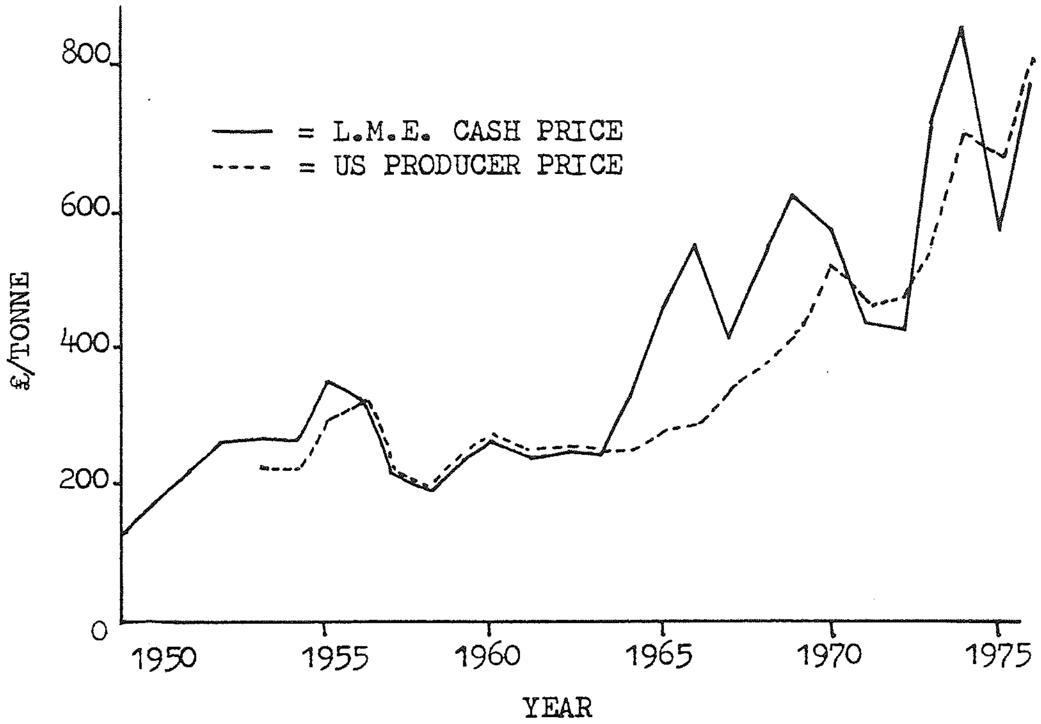


Figure 6.2 - Comparison of LME and US Producer Prices for Unwrought Refined Copper (From Appendix 2)

price changes are less frequent, less sharp and tend to lag behind LME price changes. The US is partially insulated from changes in LME prices by transportation and other costs associated with moving copper from London to New York - estimated at approximately 10 cents/lb or £90/tonne in 1978 (93). This buffer means that US producer prices have to be 10 cents/lb lower than the LME price before the producer price has to be lowered.

Although the US producer price is important to the world copper industry with 75% of North American refined copper production being sold at this price (119) the LME price is the main component in a variety of formulae used in determining prices to be paid under contract by consumers of refined copper produced outside North America. Figure 6.3 shows how the source of UK imports of unwrought refined copper into the UK changed between 1952 and 1974. It can be seen that imports from the US accounted for 12% of total imports in 1952, and only 5% in 1974. Although Canadian

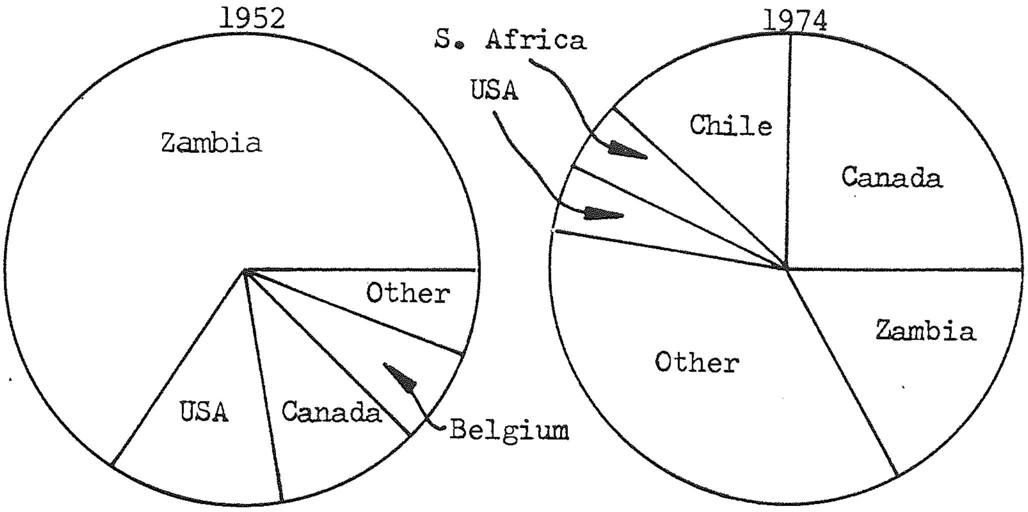


Figure 6.3 - Sources of Imported Unwrought Refined Copper for the UK (80)(105)

imports rose from 10% to 25% and total North American imports rose from 22% to 25% over the same period, Canadian sales other than to the US are based on the LME price. Consequently, the US producer price, would appear to have only a small influence upon UK refined copper supplies over the period considered but to have a much larger effect upon the world copper industry. Over the period of interest (i.e. 1949 to 1976 for which detailed data is available) a number of changes in the pricing systems have occurred. These are described in the next section.

6.3.2 Post World War II Copper Price Evolution (83, 89, 93, 96, 97)

Although the LME is often referred to as the free market price, it has been subject to a number of controls over the years. These controls and their effect must be understood to explain discrepancies between expected and actual market demand caused by price changes.

From 1939 to 1945 a fixed price for all copper sold in the UK was set by the government. At the end of the Second World War the US had become for the first time a net importer rather than exporter of refined copper with imports of 290,000 tons in 1946 and 390,000 tons in 1950. In the UK the government refused to re-open the LME, partly because the pound sterling was under pressure and eventually devalued by 40% in 1949, and (120) instead continued to act on behalf of UK refined copper consumers. Increasing world, and in particular US, demand for copper goods forced up the price at which the British Ministry of Supply had to buy refined copper. A temporary recession in the US copper industry in 1949 led to the situation where the run down of expensive UK government held stocks of copper dictated the price at which UK consumers bought copper. This had the effect of putting the UK copper industry at a disadvantage compared to foreign competition and in mid 1949 the Ministry of Supply charged the same price as COMEX.

The outbreak of the Korean War in 1950 forced the US government to impose a ceiling on COMEX prices although unofficial dealings at much higher prices took place. The end of the war in 1952 left the British Ministry of Supply with expensive stocks which again were sold at prices above those current on the world market where prices varied from producer to producer. In August 1953, the British Government handed back responsibility to the merchants by reopening the LME.

From 1953 to 1961 the market system operated as it does today, i.e. sales in the US at producers prices and, outside the USA, based on LME quotations. During this period the major integrated copper producers, at that time all private firms, gradually came to accept the idea of voluntary price stabilisation and applied it during the weak market between 1956 and 1958 and towards the end of 1960.

In late 1961 copper prices began to fall again and the three largest copper producers shored up the price by purchasing on the LME and cutting back production so stabilising copper prices through 1962 and 1963.

This period was the first since World War II where the producers controlled the LME price.

Rising prices in 1964 and concern over substitution by other metals prompted the producers to adopt a system of administered prices for 1964 and 1965 where contracts outside the US contained not the LME price, but the producers price. High demand for copper (due to the Vietnam War, Chilean strikes and reaction in Zambia to the Rhodesian declaration of UDI) and the consequent high price on the LME (to which as will be seen in Section 6.3.5 the price of scrap is linked) caused producers of copper to be converted in some cases to scrap to take advantage of the price differential. In April 1966 Chilean producers raised their price by 50% so breaking the producer price experiment and gradually all producers outside the US reverted to basing contractual prices on the LME price. Since 1967 US producer and LME prices have not differed as much as between 1963 and 1966 (as shown in Figure 6.2) although supply and demand have had an effect on their relative levels.

The discussion in the previous two sections has shown that the LME price of copper is the major price affecting the UK copper industry, remembering that between 1945 and 1953 prices were controlled by the Ministry of Supply and that the US producer price reflects the true situation affecting imports of refined copper during the producers price experiment in 1964, 1965 and 1967.

6.3.3 Deflation of the LME Copper Price

Figure 6.2 showed an irregular but general increase in the LME price of refined copper over the period 1949 to 1976. Inherent in this general upward trend is the declining value of the pound sterling reflecting increases in general prices and costs. In order to assess the real price of copper, nominal prices need to be deflated with a suitable index.

Various indices are available. The most consistent available (an important consideration when base years or levels can be changed between reports) are those produced by government statistical offices (120,121). The main cost/price indices included are:

1. Index of materials and fuels wholesale prices used in the manufacturing industries.
2. Index of the wholesale price of manufactured products.

In addition, another widely quoted and used index was abstracted (122) together with the above indices for the period 1952-1976.

3. Purchasing power of the pound based on movements in the index of retail prices.

The LME average price of copper was deflated by each of these four indices and the results plotted in Figure 6.4. It can be seen that the cost/price indices tend to produce similar results making selection of an index relatively insensitive. It was decided to use the index which refers to raw materials costs, some of which are in competition with copper for certain uses. For this reason, the index of raw materials costs was used to deflate the LME copper price.

6.3.4 Economic Theory of Copper Price Formulation

The price of copper has a far reaching effect in the copper industry affecting supply, demand, stocks and substitution by other materials. In principle, copper prices should be stabilised by a steady growing demand, slow technological change, large capital costs, consistent ore quality and lead times to develop a mine. In contrast short term copper prices are volatile in comparison to other materials. This volatility is believed (93,96) to be principally a factor of temporary

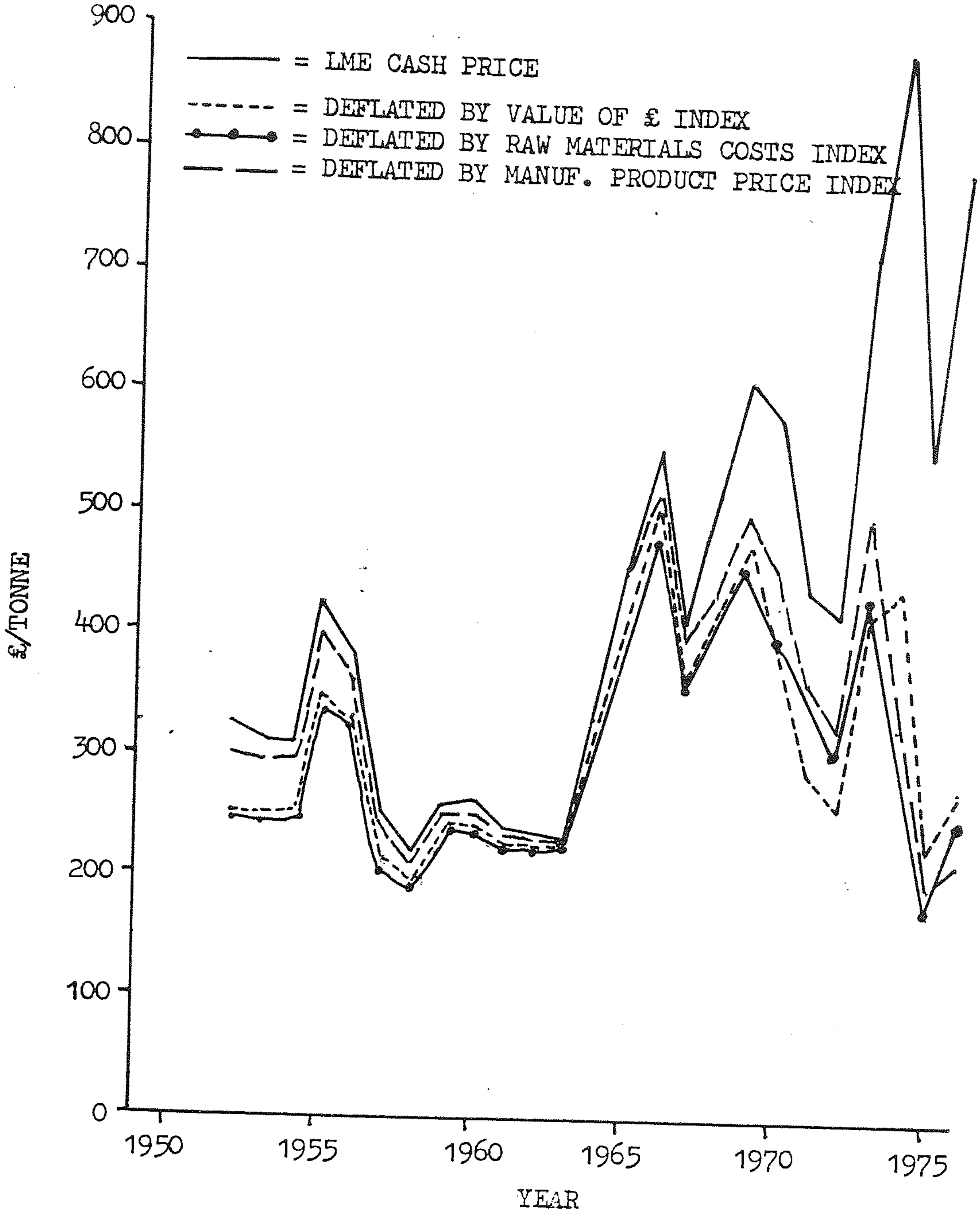
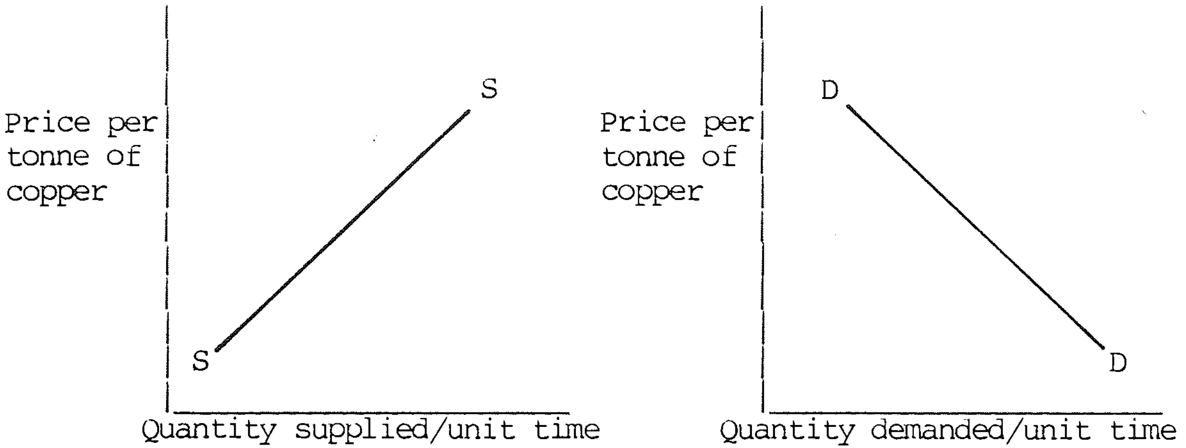


FIGURE 6.4 - DEFLATION OF LME PRICE BY VARIOUS INDICES

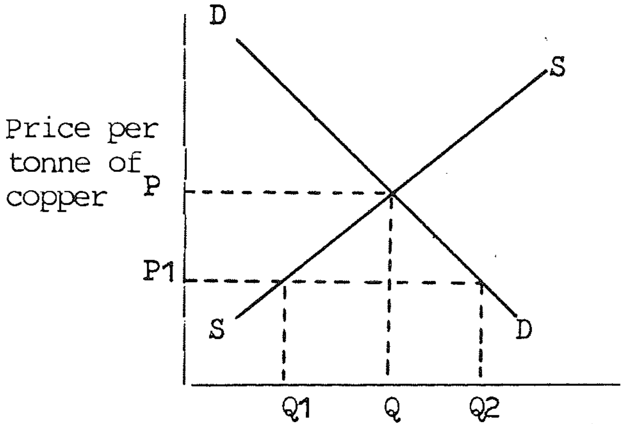
supply/demand inbalances. This section aims to investigate the mechanism of copper price formuilation but not to develop a model of copper prices, a model which is beyond the scope of this project.

Classical economic theory on the relation between prices and supply and demand is illustrated in Figure 6.5



a) Supply/price relationship

b) Demand/price relationship



c) Equilibrium market price for copper

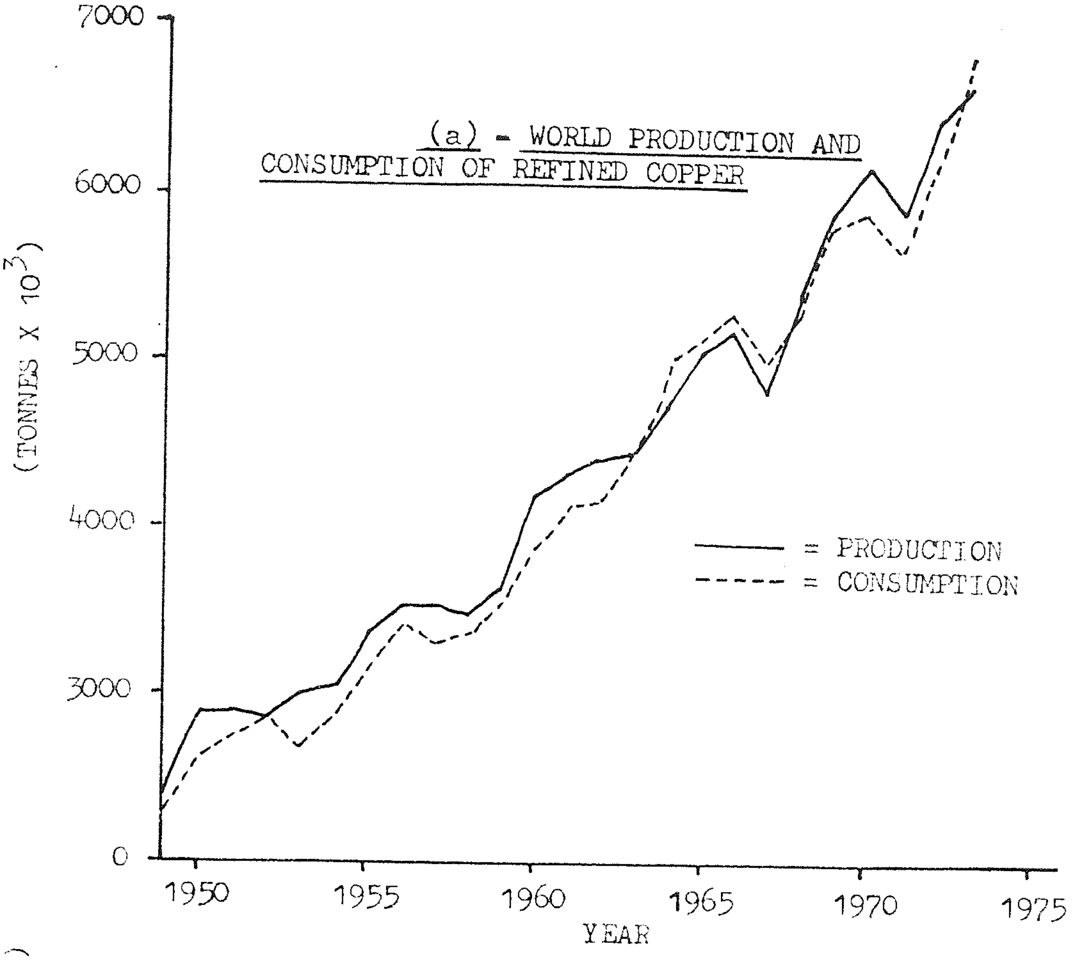
Figure 6.5 - Classical Economic Theory of Price/Demand and Price/Supply Relationships for Copper

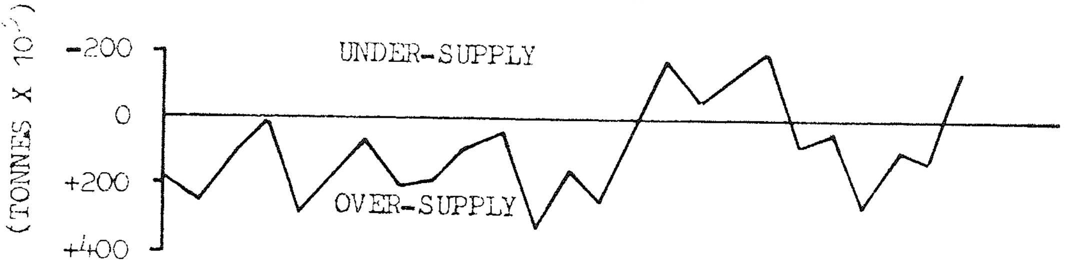
Demand (line D-D Figure 6.5(b)) is considered to react to price, reducing demand as prices rise. In contrast supply (line S-S Figure 6.5(a)) increases as prices rises occur. The interaction of these two relationships is shown in Figure 6.5(c) where the equilibrium price P which consumers are prepared to pay (line D-D) equals the price at which producers are prepared to sell (line S-S). AT this equilibrium price P a quantity Q of copper will pass through the market system. The effect of a lower price P_1 would be to imbalance supply to point Q_2 and demand to Q_1 which would encourage the price to rise back towards the equilibrum level P (123,124).

As the price of copper on the LME may be considered a world price, (section 6.3.1) supply/demand relationships on a global level need to be investigated to see if copper prices do follow the classical theory of supply/demand. Figure 6.6 shows World (excluding Centrally Planned Economies (CPE's)) production and consumption of virgin refined copper together with the overall supply/demand balance and the deflated price of copper from Section 6.3.3.

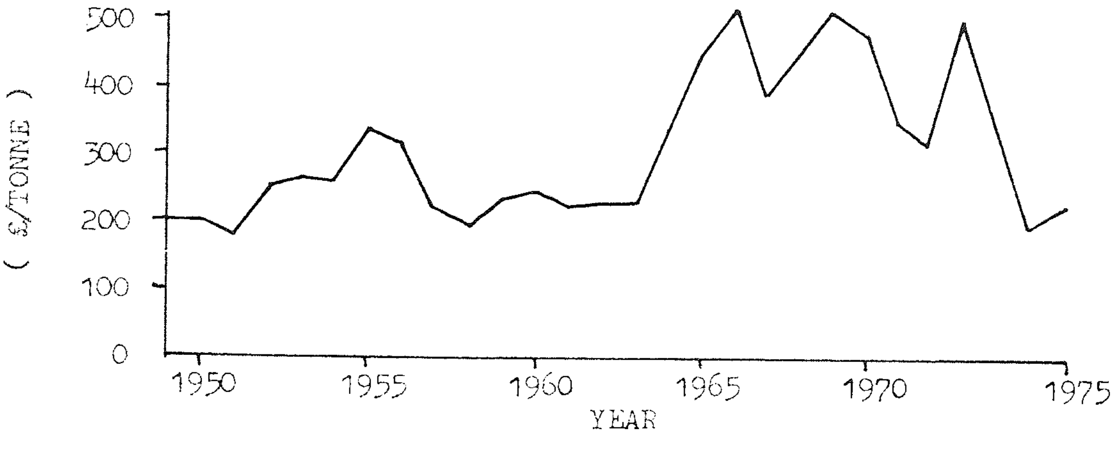
Figure 6.6(a) shows that a steady increase in demand for refined copper has occurred with only periodic fluctuations. World demand for refined copper has been found to fluctuate over periods of 4-5 years in a similar manner to that recognised in Section 5.7.1 for the UK. This 4-5 year cycle corresponds to a similar cycle in world industrial production. Examination of the relationship between copper prices and a global industrial production index has shown that commodity prices including coppers fall in spite of continuing rises in industrial production (83) with a rule of thumb being that prices are relatively stable when industrial production is growing at 5% per annum. Prices tend to rise at a faster rate of industrial production growth than 5% and so aggregate world demand for copper will depend upon the extent to which different countries economic cycles are in phase.

The supply of copper shown in Figure 6.6(a) has grown at a similar rate to demand and while subject to the demand cycle of 4-5 years has also been found (83) to include a long term capacity cycle of approximately 14 years with the last period of overcapacity occurring around 1965.


(a) - WORLD PRODUCTION AND CONSUMPTION OF REFINED COPPER



(b) - WORLD SUPPLY/DEMAND RELATIONSHIP FOR REFINED COPPER



(c) - LME PRICE OF REFINED COPPER DEFLATED BY RAW MATERIALS COST INDEX

FIGURE 6.6 - WORLD COPPER SUPPLY AND DEMAND RELATIONSHIP AND THE PRICE OF COPPER

This is shown in Figure 6.6(b) where the extent of the inbalance between supply and demand for copper is shown.

Although a correlation between copper prices and supply/demand for refined copper exists with prices peaking every five years or so, with a strength dependent upon the underlying capacity utilisation, these trends do not completely explain the volatile nature of copper prices. Prain (125) and Meadows (126) amongst others, have drawn atention to the effects of stock level changes on copper price movements. The stocks in question are those held by producers, LME and COMEX., fabricators and in government stockpiles and are an important component of an econometric model (Section 6.2.4). The level of world stocks is difficult to ascertain and the only stocks for which data is readily available are those held by LME members. Meadows (126) examined the relationship of LME stocks and the LME cash price for copper in 1974 and the results are reproduced in Figure 6.7. 1974 was an unusual year for the marked changes in prices and stocks that occurred and the relationship displayed in Figure 6.7 does appear to be very good.

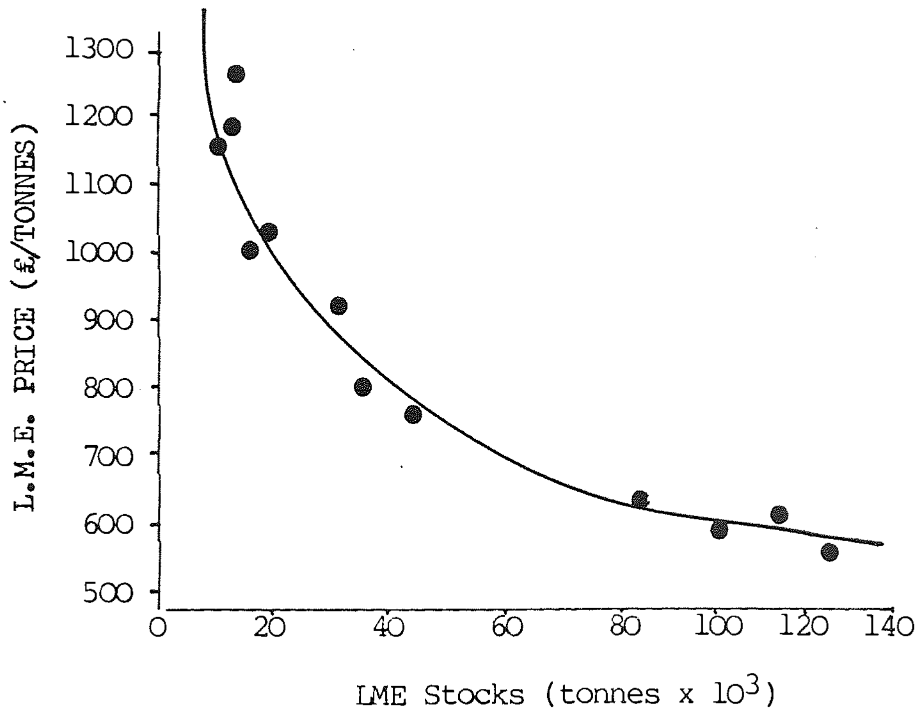


Figure 6.7 - Relationship Between LME Cash Price and LME Stocks for 1974 (126)

Unfortunately taking Meadows work over a number of years produces inconsistent results as seen in Figure 6.8, where, due to lack of data, deflated LME price changes have been plotted against LME stock changes for the years 1949 to 1976 - a modified form of Figure 6.7. It can be seen that no clear correlation as shown by Meadows in Figure 6.7 exists and it must be concluded that stocks not only change in the short term with price but may also be influenced in the long term by world supply and demand balances in a similar fashion to the mechanisms described earlier.

It is not the intention here to provide a model for copper prices as this would be too complicated and preclude achievement of the overall project objective. A practical model to be used for forecasting price movements would need to include industrial production and capacity cycles, stock changes, supply and demand together with temporary factors such as strikes. Some models have been developed but will only be referred to in a later section where forecasts of copper prices are required.

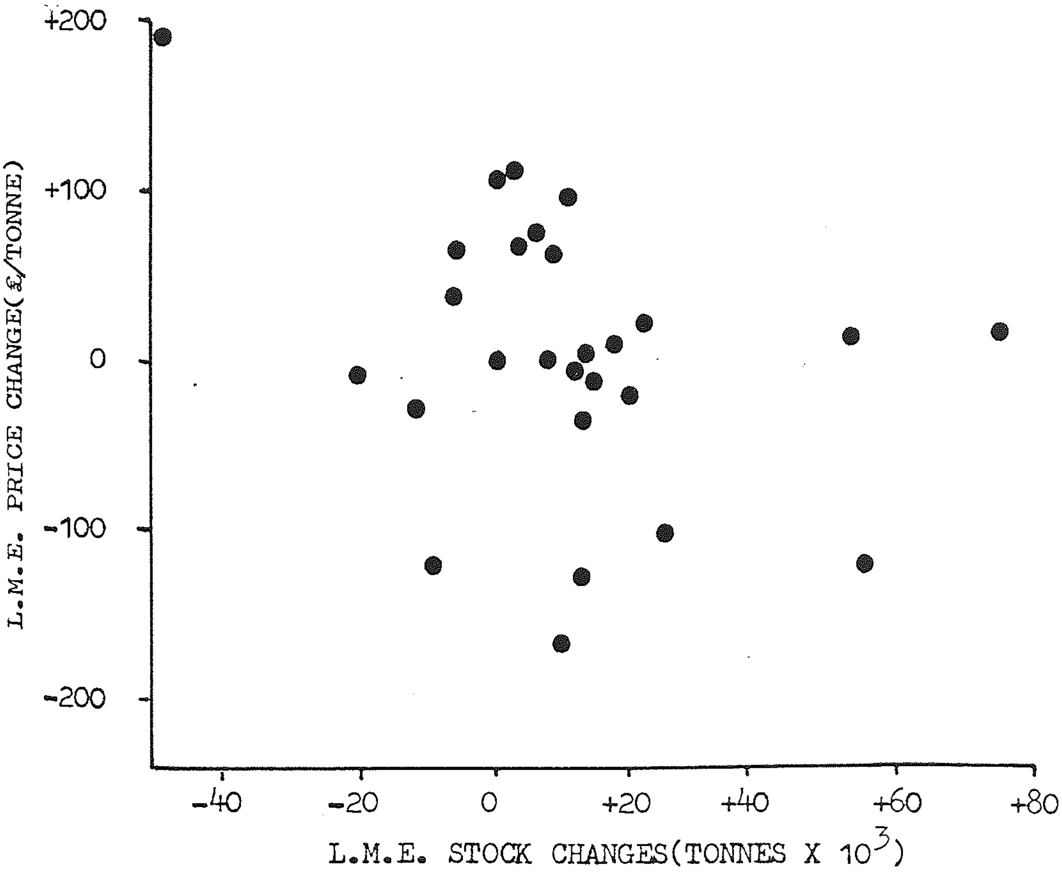


Figure 6.8 - LME Stock Changes and LME Price Changes 1949 - 1976

6.3.5 The Relationship Between Refined and Scrap Copper Prices

Copper scrap is used in many diverse ways ranging from direct-uses to refining processes (Section 4.2) and it arises in many different grades (Section 4.2.9). Price has already been determined to be a major factor in primary copper demand (Section 6.3.4) and a similar situation may exist for scrap copper. It is therefore important to include scrap prices in any model of secondary copper supply and demand.

The wide range of scrap grades available and lack of data (Section 5.7.4) on the relative importance of each grade means that an alternative to individual scrap grade prices has to be found.

Figure 6.9 shows LME cash prices for refined copper together with average annual prices for No.1 copper wire scrap (a high grade scrap) and Braziery (a low grade alloy scrap). A close correlation between the LME price and scrap prices can be seen although the gap tends to widen when the price is higher. This may be due to an upper limit to the quantity of old scrap which can be used by scrap consumers, and in particular the direct-users of scrap.

Labys, Rees and Elliot (127) investigated the correlation shown in Figure 6.9 for various scrap grades using cross-sectional spectral analysis, a complex time-series analysis. Scrap prices were found to vary randomly (as do LME prices for refined copper) although a slight seasonal cycle of four months was found for both LME refined and No.1 copper wire prices. While LME prices did not lead No.1 copper wire prices, other scrap grades were led by approximately two months, possibly corresponding to the 45-70 days required to refine secondary copper. No.1 copper wire may be used directly by the semi-manufactuers and so would not be expected to lag behind LME prices.

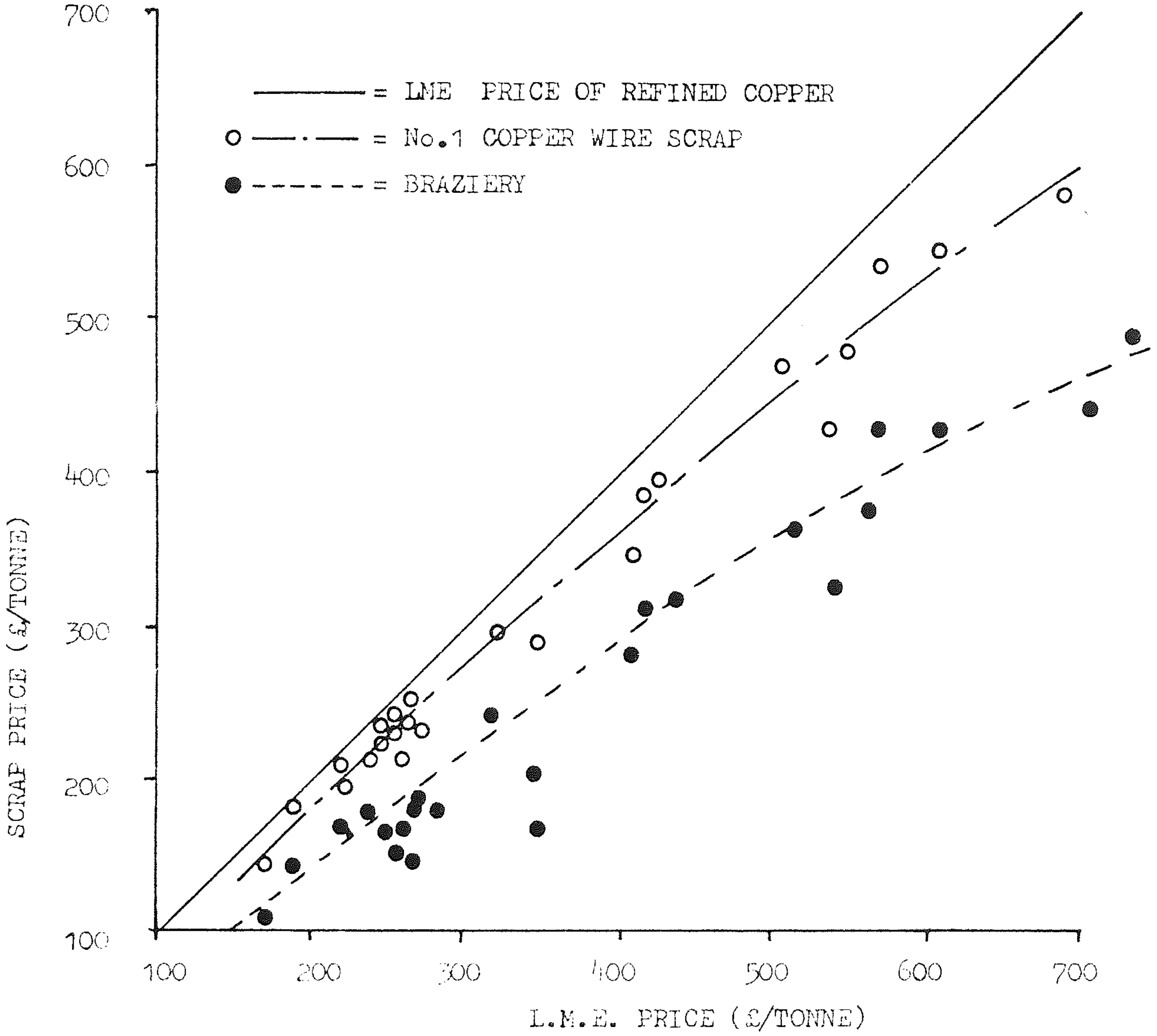


FIGURE 6.9 - No.1 COPPER WIRE AND BRAZIERY SCRAP PRICES COMPARED TO LME CASH PRICES FOR REFINED COPPER, 1949-1976

The results obtained by Labys, Rees and Elliot, combined with the above analysis show that a correlation between LME refined prices and scrap prices exist and that the annual nature of the data used in this work means that the more readily available LME refined copper prices may be used to reflect scrap prices.

6.4 Summary to Chapter 6

An examination of the various modelling methods available resulted in the selection of a relatively simple causal model consisting of individual equations without producing mutually exclusive solutions. Regression analysis will be used relating to available literature in data and economic factors.

The various refined copper prices have been examined and their relevance to the UK assessed. The LME price of refined copper, as well as being a world market clearing price, is the major component affecting the price paid for UK refined copper imports.

Post-war copper prices have been reviewed and it was concluded that while the LME price was a free market price over most of the period in question, the effect of price control experiments attempted at various times must be remembered.

Various methods of deflating the LME refined copper price were examined and deflation by an index of materials and fuels wholesale prices used in manufacturing industries selected, although other indexes provide similar results.

The economic theory of copper price formulation has been discussed with respect to global supply and demand of refined copper. It was found that rates of growth in global industrial production of 5%/annum result in relatively stable copper prices and that higher or lower growth rates tend to destabilise copper prices. Modelling of copper prices was declared to be beyond the scope of this project, in itself being a very complicated problem. Instead, reference will be made to published projections of copper prices.

Finally, the relationship between refined copper and copper scrap prices was reviewed and a close correlation between the two prices identified. This correlation means that the more readily available LME refined copper prices may be used in later models to represent scrap copper prices.

CHAPTER 7 MODELLING U.K. DEMAND FOR COPPER GOODS

7.1 Introduction

The decision to model UK demand for copper goods was made on the following grounds:-

It has been explained in Chapter 5 that statistics on copper demand are more readily available than for copper scrap. This means that if the available statistics developed in Chapter 5, supplemented by other published data, are insufficient to satisfactorily model UK demand for copper goods, then accurate modelling of UK scrap flows will be an extremely difficult task.

Additionally, a methodology will be developed to model demand for copper goods which will then be applied to UK scrap flows. An interesting parallel between the more readily understood competition between copper and its substitutes, in the case of demand for copper goods and the primarily unknown mechanisms of competition between primary and secondary copper, in the case of demand for scrap copper may prove useful in the next Chapter.

Finally, demand for copper goods will affect demand for scrap copper and will also affect future scrap supplies.

7.2 Measures and Trends of U.K. Demand for Copper Goods

7.2.1 Measures of U.K. Demand for Copper Goods

The copper production process is shown in Figure 7.1 (abstracted from Figure 5.1).

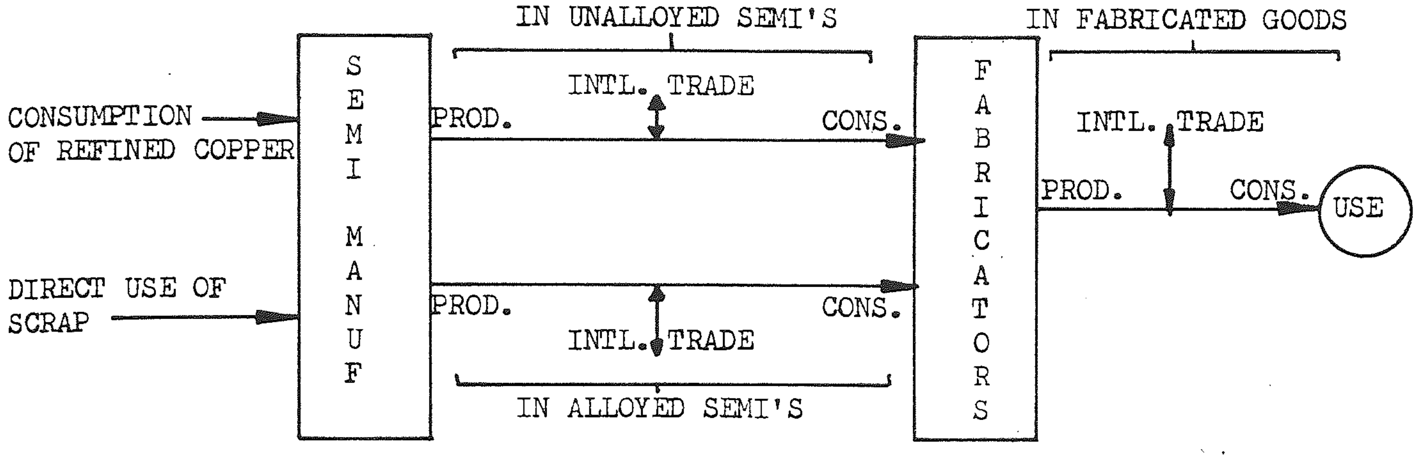


Figure 7.1 - Various Measures of U.K. Overall Demand for Copper

Ideally, UK overall demand would be measured by the consumption of fabricated goods by the consumer. Unfortunately, as explained in Section 5.7.3 data limitations make it very difficult to measure UK consumption, international trade and production of fabricated goods. However, by moving further back up the production process the first measure for which a reliable time series may be determined is the consumption of semi-manufactures, which may be disaggregated into unalloyed and alloyed semi manufactures. Although this measure ignores losses due to fabrication efficiencies, i.e. new scrap generation, as explained in Chapter 5, new scrap is assumed to be a constant proportion of semis consumption and for the purpose of this chapter may be ignored.

7.2.2 Trends in U.K. Demand for Copper Goods

Figure 7.2 shows UK total, unalloyed and alloyed semis consumption produced from data in Section 5.7.2 where the trends in these flows were discussed. A more useful means of examining trends in demand, particularly in relation to population and standards of living, is to consider trends in:

1) per capita copper consumption

2) intensity of use (copper consumption per unit of GDP)

3) rate of growth in consumption relative to the growth of industrial production.

This has been done in Table 7.1 and Figure 7.3.

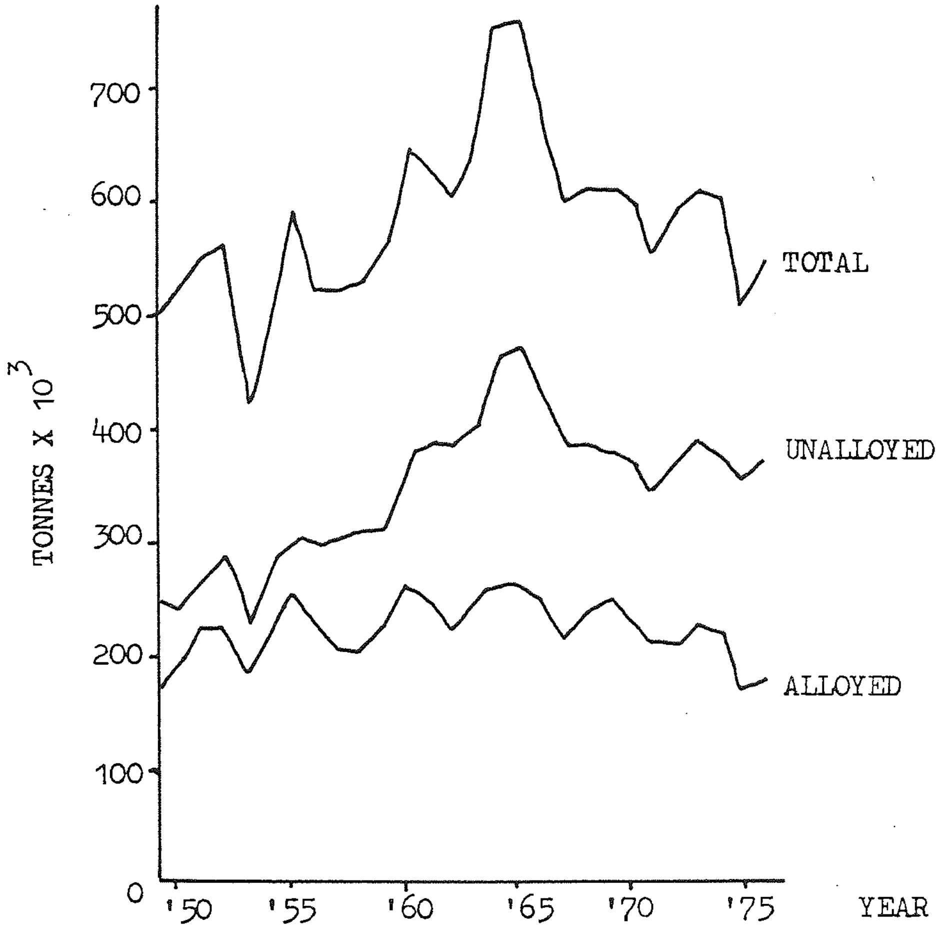


Figure 7.2 - Unalloyed, Alloyed and Total Semis Consumption

SOURCE: FIGURE 5.12

Table 7.1 - Per Capita and Intensity of Use Coefficients for UK Copper Semis Consumption

Period	Per capita consumption[(a)] tonnes/thousand population	Intensity of use [(b)] tonnes/£million GDP
1950 - 1954	9.7	18.6
1955 - 1959	10.7	18.3
1960 - 1964	12.4	19.0
1965 - 1969	11.8	16.1
1970 - 1974	10.5	12.2

Sources: (a) Population data from Economic Trends (122) and UK Key Stats (121)

(b) GDP based on expenditure data, 1970 prices (122).

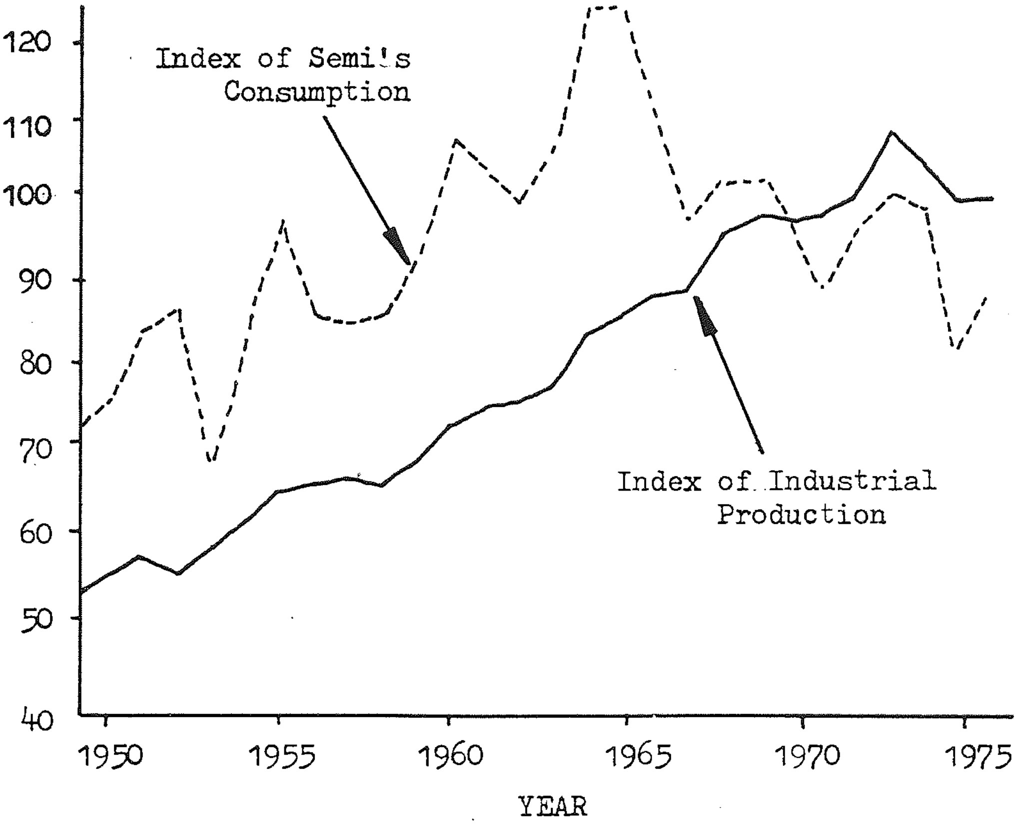


Figure 7.3 - Indices of UK Copper Semis Consumption and Industrial Production

Sources: Economic Trends (122) and Chapter 5.

All three indicators of copper demand exhibit a similar trend, a period from 1949 to 1960-1964 where per capita consumption increased, intensity of use remained stable and growth in the indices of industrial production and semis consumption were parallel. Since 1960 - 1964 both per capita consumption and intensity of use have fallen signficantly with a similar trend exhibited by the indices of industrial production and semis consumption.

In contrast, Gluschke (93) found that per capita consumption of copper increased in other major industrialised nations over the period 1963-1974. Gluschke suggests that the close similarity of per capita consumption figures for the UK, Japan and the U.S.A. indicates a saturation level in demand of 9-10 tonnes/thousand population i.e. lower than in Table 6.3. Gluschkes figures are taken from an unreferenced Commodities Research Unit report. No details of how copper consumption is measured are given by Gluschke although the figure of 10.4 tonnes/thousand population for 1963 equates approximately to the consumption of refined copper by the semi-manufacturers. If this is the case then the effects of scrap and international trade in semis have not been considered and the figures given in Table 7.1 for the UK are a more accurate measure even though, as explained earlier, even these figures do not take into account international trade in fabricated goods.

The intensity of use of copper has been found (122) to be closely correlated with that of steel. Malenbaum (122) concluded that the role of copper in electrification and capital projects due to its conductive properties accounts for the upward trend in intensity of use observed in Table 7.1 and that, in common with Germany, Italy, Japan and the U.S., eventual completion of electrification accounts for the fall in demand in more recent years.

The trends in industrial production and copper consumption seen in Figure 7.3 for the UK have been found (93) to be similar to those for other industrialised countries with the exception of Japan where rapid rises in industrial production has been matched by similar rises in copper consumption.

The above examination shows that the historical picture of increased copper consumption induced by general economic growth is no longer applicable to the UK. The relative complexity of the UK copper industry and the difficulty of producing causal models has resulted in no models of UK copper demand being produced after 1970, when the simplistic type of model described above became inapplicable.

7.3 Model Development

Many authors have qualitatively described the factors affecting UK demand for copper goods, but no quantitative analysis for the UK has been found. This is surprising in view of the importance of copper to the UK economy and in particular the large volume of refined copper imports to the UK.

In the U.S.A., the modelling of copper demand has been examined in more detail, but has little relevance to the UK because unlike the UK, US domestic mines supply the majority of refined consumption using a pricing system different to that for the UK (section 6.3.1).

Two models were found which attempted not only to model the US copper industry but also the Rest of the World copper industry. These are by Fisher (129) and Charles River Associates (130). Both models were produced in the early 1970's and are too lengthy to be reproduced here.

NO PAGE 223

Fisher (129) failed to model total copper demand in individual European countries, although aggregate European demand was modelled reasonably well. The factors included in the model were:

(1) The current index of industrial production,

(2) (1) lagged by one year,

(3) the LME copper price,

(4) the price of aluminium,

(5) copper demand lagged by one year.

The model of U.S. demand was very successful ($r^2 = 0.991$) with current and lagged copper prices, lagged aluminium prices, the index of industrial production, lagged demand and current and lagged general stock changes. The inclusion of stock changes is discussed in more detail later and is an important aspect of modelling copper demand.

Fisher concluded that copper demand is rather inelastic with respect to copper prices, even in the long run and that aluminium prices do have a long term effect. The most important determinant was found to be levels of industrial activity.

The second model of copper demand was by Charles Rivers Associates (CRA) (130) as part of an economic analysis of the factors affecting the USA copper industry in order to forecast copper demand. The first model developed was disaggregated into wire mill, brass mill and foundry products and multicollinearity between variables was thought to be the major reason for its failure. The more successful aggregate model of total demand included:

(1) the deflated price of copper,

(2) the deflated German price of aluminium,

(3) demand lagged by one year,

(4) changes in durable good stocks,

(5) an index of durable manufactures production.

This model is very similar to Fisher's model differing in the definition of the price variable, although the CRA model does examine the effects of using various prices, including that of scrap whose effect was found to be small. The conclusions from the CRA model were that demand is highly price inelastic in the short-run but, in contrast to Fisher's model, very price elastic in the long run with similar conclusions for the price of aluminium. Once again, the CRA model found that the lagged value of stocks of durable manufacturers was highly significant as it "hides" true demand.

In the remainder of this section, factors considered to have an effect on copper demand, identified from the quantitative models above, and qualitative statements in other works will be discussed prior to proposing various models of UK copper demand.

Gluschke (93) refers to a model of unknown origin which relates copper demand to various factors already identified above, although the price of aluminium was lagged by seven years - equal to a business cycle. Whether other lags were investigated is not indicated and lags up to seven years will be investigated in this work.

7.3.1 The Dependent Variable - Demand

As explained previously, the demand for copper is to be investigated in two ways. In the first copper demand will be disaggregated into unalloyed and alloyed semis consumption while in the second aggregate semis consumption will be modelled.

In order to provide a more accurate measurement of demand the semi's consumption data needs to include changes in the stock levels of semis held by fabricators i.e. demand (D_t) = semis consumption ± stock changes in semis. Unfortunately, as explained in Section 5.7.3 no complete time series is available for these stock changes. However, time series are available (122) for stock changes relevant to general economic activity including stock changes for materials and fuels, work in progress and fabricated goods. If it is assumed that the change in semi's stocks held by fabricators is linearly related to one of these general stock level changes then a more accurate measurement of demand may be made.

Examining available UK stock change time series the change in stocks of materials and fuels published in Economic Trends (122) would appear suitable, although the work-in-hand stock change could be relevant to goods awaiting further fabrication. In view of this, both stock changes were used. The stock changes are measured in million pounds sterling and were deflated by the index of wholesale prices of materials and fuels (122).

An interesting aspect of the inclusion of stock changes involving the relationship between general and semi-manufacture stock changes where a linear relationship is assumed to occur i.e.

$$\Delta I_t = \alpha + \beta \ \Delta I_t^G$$

where ΔI_t = copper semi manufacturers stock changes in year t

ΔI_t^G = an index of general stock changes

α and β = constants.

and if the demand equation excluding stock changes is given by

$$D_t = a_o + a_1 X_t + a_2 D_{t-1}$$

where X_t = all the other variables in the demand equation

a_o = constant

a_1, a_2 = coefficients

then the corrected demand equation is:-

$$D_t - \alpha - \beta\Delta I_t^G = a_o + a_1 X_t + a_2 (D_{t-1} - \alpha - \beta\Delta I_{t-1}^G)$$

rearranging

$$D_t = (a_o + \alpha - a_2\alpha) + a_1 X_t + \beta\Delta I_t^G - a_2 \beta\Delta I_{t-1}^G + a_2 D_{t-1}$$

This means that both ΔI_t^G and ΔI_{t-1}^G should be included and additionally that the coefficient of ΔI_{t-1}^G should be minus the product of the coefficient of ΔI_t^G and D_{t-1} thus providing a check upon the accuracy and validity of the demand model.

7.3.2 Lagged Demand

In the discussion of factors affecting demand for copper it has been assumed that reactions to change in the copper industry are not instantaneous, but take a finite time to occur. An econometric type model of the copper industry requires the dependent variable, in this case demand, to be influenced by past as well as present independent variables i.e. an adaptive expectations type model (130) which assumes that users adjust their demand, D_t, according to the rule:

$$D_t - D_{t-1} = \lambda (D_t^* - D_{t-1}) \qquad 0 \leqslant \lambda < 1 \qquad (E1)$$

where D_t = demand in year t, or actual demand

D_{t-1} = demand in year t-1

D_t^* = long run equilibrium demand or desired demand

λ = speed of adjustment coefficient.

The coefficient λ is the fraction of the gap between desired and actual consumption which users make up during a single year. The explanation is completed by a statement of how the long run equilibrium level of demand is selected. For example, if

$$D_t^* = a_o + a_1 P_t + a_2 X_t \tag{E2}$$

where P_t = price

X_t = other influences on demand

then current demand is given by (E1) rearranged as:-

$$D_t = (1-\lambda) D_{t-1} + \lambda D_t^* \tag{E3}$$

and

$$D_t = (1-\lambda) D_{t-1} + \lambda a_1 P_t + \lambda a_2 X_t + \lambda a_o \tag{E4}$$

By obtaining similar expressions for D_{t-1}, D_{t-2} etc. and substituting these into (E4) and rearranging we obtain:

$$D_t = a_o + \lambda a_1 \sum_{\theta=0}^{\theta=\infty} \mu^\theta P_{t-\theta} \quad \mu = 1-\lambda \tag{E5}$$

This expression gives the relationship that demand in year t depends upon both present and past prices with the weightings given to past prices decreasing geometrically with the length of the lag.

In (E5) the short run effect of price on demand is given by λa_1, and the long run effect by a_1, as eventually the sum of the λ terms becomes unity. If λ is relatively small so that adjustments take place slowly, long term effects will be more significant.

In fact there are several sets of initial assumptions which will lead to E5 (129,131) with Fisher (129) presenting an analysis of their validity.

In this modelling exercise, progression to equation E5 is not necessary as inclusion of the dependent variable lagged by one year in the model produces E4 where it can be seen that the speed of adjustment coefficient, λ, is the coefficient of the lagged demand variable. Reference to the previous section shows that the inclusion of the general stock change variable does not affect the coefficient of lagged demand, a_2, which may be replaced by λ.

7.3.3 Activity Level

Since copper semis are an intermediate product in the fabrication of goods, their consumption depends very strongly on the demand for the final products in which they are used. The breakdown of end-uses of copper given in Section 4.3 showed that indexes relevant to the activity of the electrical; construction; general engineering; road, rail and sea transport; and domestic consumer goods industries are necessary.

Indexes specific to these industries are not readily available but close examination of the end-use industries listed in section 4.3 reveals that they are closely related to the general level of economic activity for which various indexes are available (122). An additional problem in using indexes for each end-use would be the multi-collinearity which would adversely affect the accuracy of the model.

The indexes available include indexes of industrial production for the mining and quarrying, manufacturing, construction, gas, electricity and water industries. The all industries index of industrial production has the following weightings: mining and quarrying, 37; manufacturing, 745; construction, 146; gas, electric and water, 72. As the major weightings are given to the indexes of manufacturing and construction the all industries index of industrial production will be used in the models to account for activity levels.

7.3.4 The Price of Copper and Substitutes

For many years, copper has been regarded as being under strong threat from other materials, in particular aluminium, plastics, stainless steel, sodium metal, titanium, lead cadmium and niobium, and it is possible that substitution of copper by these materials can account for the patterns shown above. However, none of these materials is a perfect substitute - the unique chemical and physical properties of each one means that a balance between useful and detrimental properties must be acceptable to the producer and consumer.

Substitution can occur in one of three ways, two of which account for major substitutions for copper and one way which may loosely be classified as substitution as identified by Gluschke (93). This latter case, sometimes referred to as quantitative substitution, refers to the reduction of copper per unit of output i.e. where copper is still the cheapest material available to satisfy the design criteria, but costs can be reduced by economising on its use. This type of substitution is more commonly referred to as economy-of-use.

Physical substitution on the other hand refers to the substitution of another material for copper because of the formers relative cheapness per unit of desired property.

Finally, invisible substitution refers to the situation where a new product is introduced to the market and a rival material is used instead of copper. All three types of substitution have affected copper, a good example being automobile radiators where there has been quantitative substitution through the use of a lower volume of brass (rather than copper) per radiator; physical substitution where aluminium or stainless steel has been used for radiator fins and invisible substitution where copper has been virtually eliminated from the cooling system of the VW Golf in favour of plastics and stainless steel (132). Any model of UK demand for copper goods must include one or more variables to account for substitution.

The materials most frequently quoted as substitutes for copper are aluminium, stainless steel, plastics, zinc, nickel and lead. The intrinsic merits of these materials vary but in most applications, copper faces competition from at least one material. One source (21) estimated the proportion of each end-use of copper where copper is unlikely to be substituted and this information has been reproduced in Figure 7.4.

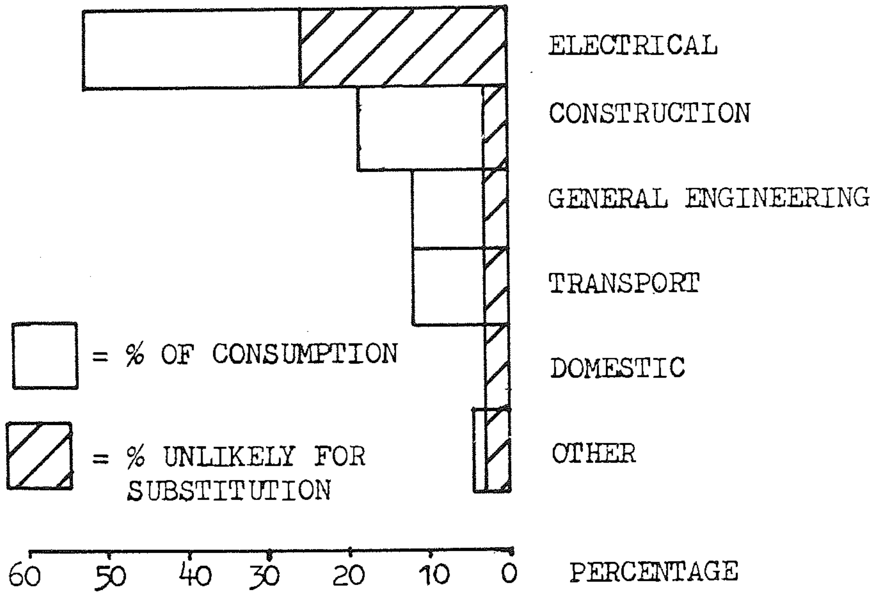


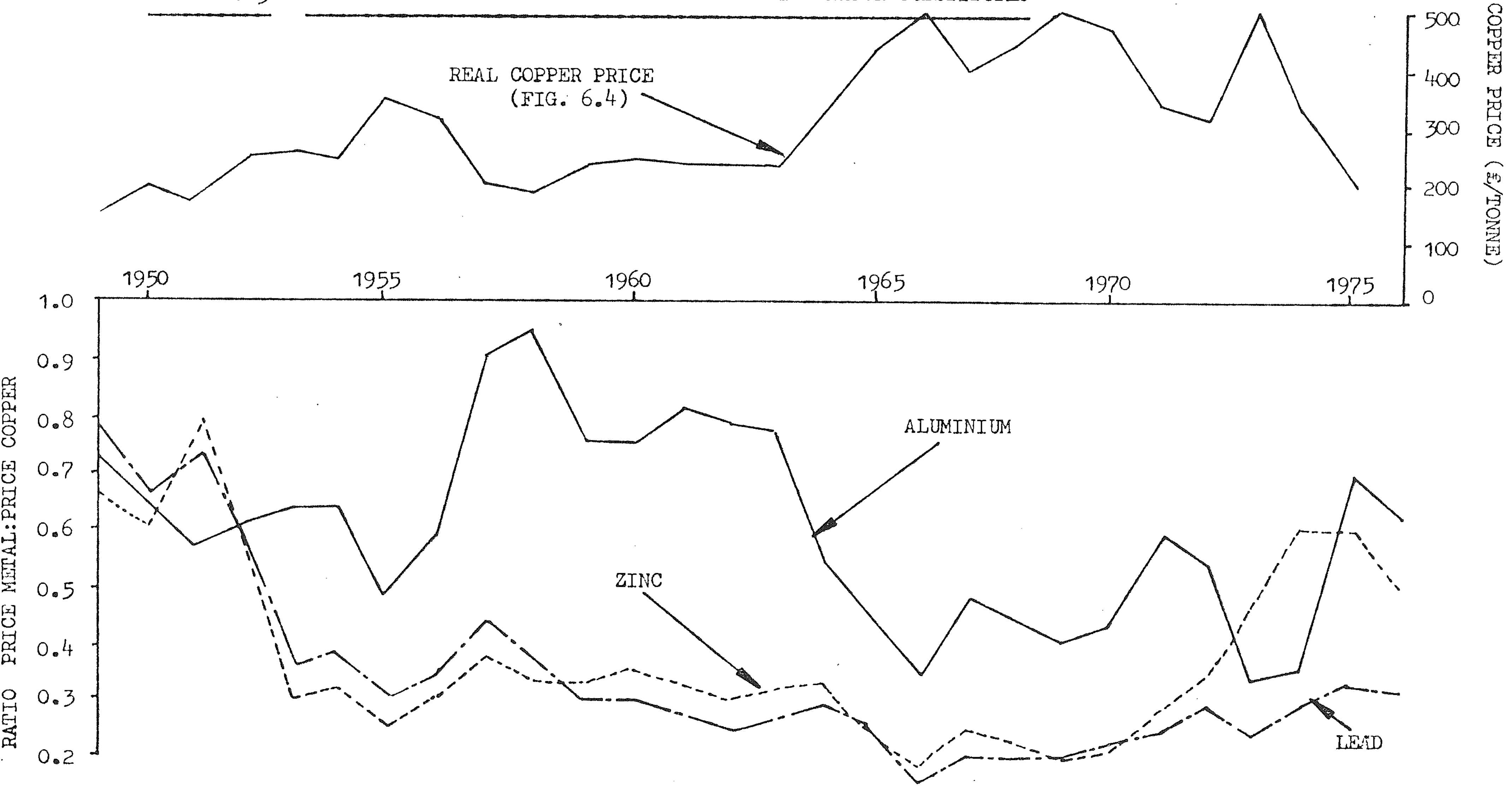
Figure 7.4 - Uses of Copper for Which Substitution is Unlikely (21)

where it can be seen that the electrical applications of copper are the least likely for substitution but that all other uses are open to substitute materials. Overall 40% of copper consumption is unlikely to be substituted for by other materials.

The substitution of copper may be divided into short run and long run substitution. In short term substitution another material is temporarily or permanently used instead of copper because of relative price levels. For instance, for technical reasons, copper pipe is preferred to plastic pipe or cast iron pipes for drainage, but if the price of copper pipe becomes too high then the building contractor will use substitutes. When the price of copper pipe falls he will revert back to using copper. Qualitative information on copper demand does not provide a solid basis for estimating the importance of short run substitution although it would be expected to follow movements in the relative price of copper and its substitutes. Figure 7.5 shows these movements together with the deflated price of copper over the same period. Zinc and lead prices have generally been at a constant ratio of copper prices making short term substitution unlikely. In comparison, coppers principal competitor, aluminium, has shown definite fluctuations in relative price over the entire period. These fluctuations can be directly linked to the price of copper also plotted in Figure 7.5 showing that over the period considered the price of aluminium was stable compared to the volatile copper price.

The long term trends in relative prices affect the long-term substitution of copper. The copper user does not want to scrap his existing substantial investment in copper working machinery but knows that he would be correct in doing so if the price of copper was going to stay uncompetitive for a period necessary for him to recover his

FIGURE 7.5 - RELATIVE PRICE MOVEMENTS OF COPPER AND ITS MAJOR SUBSTITUTES



investment costs. In this context, the notorious instability of copper prices compared to the administered aluminium price has been a major factor in substitution decisions rather than the level of copper prices themselves, since an unpredictable price adversely affects planning and budgets.

The producers of copper are only too aware of the need to control prices to prevent the drift to aluminium and other materials. Various attempts, such as the producer price experiments in the 1960's (section 6.3.2) have been made to control price but only with limited success.

The decision to switch from copper to aluminium may take several years as tools and processes are changed, but the major danger to copper is invisible substitution from new plants using aluminium and not copper from the outset and not having to write off existing equipment before it has fully depreciated (132,134). Additionally, a long term high price of copper will produce innovations opening up previously safe areas to substitution. For example, aluminium automobile radiators were uncommon because of the difficulty of welding aluminium until recently when suitable techniques were developed - whether this development can be traced back to the high copper prices of the early 70's is open to doubt but possibly research programmes were triggered at this time. The above analysis suggests that a short term and long term relative price of aluminium, the principal substitute for copper should be included in the demand model.

The U.S. developed models of copper demand (129, 130) used the German price of aluminium deflated by an appropriate index for each of the regions considered including the U.S. Similar explanations are given in both reports that the U.S. producers price of aluminium is an administered price which, like the U.S. producer price for copper, is changed infrequently.

Unlike the copper price, however, the U.S. aluminium price is often an unrealistic quotation with heavy discounting or rationing taking place and is not a suitable price for comparison with the free market price of copper. The LME price for aluminium was also controlled for part of the period in question i.e. until mid 1953 and so the deflated German price was used.

In this work, the U.K. market for copper is being investigated and so the LME price of aluminium deflated by the index of raw material costs will be included in the model as well as the deflated copper price.

To provide a more direct link between copper and aluminium prices the ratio of aluminium to copper prices was included as an additional variable. In order to investigate short term and long term substitution patterns deflated copper and aluminium prices, as well as their ratios, will be lagged by varying amounts.

7.3.5 Summary of Model Development

The analysis in the previous sections suggests that U.K. demand for copper goods, measured either by total, unalloyed or alloyed semis consumption, is principally a function of five factors:-

1) The price of copper
2) The price of aluminium
3) The index of industrial production
4) Demand lagged by one year
5) Current and lagged values of industrial stock changes.

To investigate the relevance of the above list various models will be constructed using empirical measures of the factors given, as shown in Table 7.2.

Table 7.2 - Major Specific Variables to be Used in Modelling U.K. Demand for Copper Goods

1. Total semis consumption	Dependent variables
2. Unalloyed semis consumption	
3. Alloyed semis consumption	
4. Real price of copper	Current values of independent variables
5. Real price of aluminium	
6. Ratio of price of aluminium to price of copper	
7. Index of industrial production	
8. Change in material and fuel stocks (£ deflated)	
9. Real price of copper, lagged by one or more years	lagged values of independent variables
10. Real price of aluminium, lagged by one or more years	
11. Ratio of aluminium price to price of copper, lagged by one or more years	
12. Index of industrial production, lagged by one or more years	
13. Change in material and fuel stocks, lagged by one or more years	
14. Total semis consumption, lagged by one year	Lagged dependent variables
15. Unalloyed semis consumption, lagged by one year	
16. Alloyed semis consumption, lagged by one year	

7.4 Model Results

7.4.1 Introduction

The variables listed in Table 7.2 may be combined in various ways (see Appendix 1) and over 200 models were tested using regression analysis. Many models gave statistically unacceptable results and, in particular multiplicative and complex models did not improve on the simpler additive models. Lags greater than one year did not improve the model results.

Table 7.3 shows the specification for 24 additive models found to be the most suitable for modelling demand for copper goods.

In the 24 models, lagged demand is always included, supporting the adaptive expectation type of causal model. Four measures of copper and aluminium prices are included; current prices of copper and aluminuim, the prices of copper and aluminium lagged by one year; the current ratio of copper and aluminium prices and the ratio of copper and aluminium prices lagged by one year. For each of these four measures of copper price,models were constructed which included and excluded current and lagged stock change variables.

Finally,the break between copper demand and industrial production after 1964 noted in Section 7.2.2 led to the inclusion of models which included and excluded this index. These models were constructed both for the total period considered and for the period 1964 - 1976 to investigate any changes.

Table 7.3 - Specifications for additive models of copper demand

Model No.	Real Price of Copper (t)	Real Price of Aluminium (t)	Real Price of Copper (t-1)	Real Price of Aluminium (t-1)	Ratio of Price AL to Price CU (t)	Ratio of Price AL to Price CU (t-1)	Index of industrial production (t)	Deflated Material & Fuel Stock (changes) (t)	Deflated Material & Stock changes (t-1)	Lagged Dependent variable
1	✓	✓					✓			✓
2	✓	✓					✓	✓	✓	✓
3			✓	✓			✓			✓
4			✓	✓			✓	✓	✓	✓
5					✓		✓			✓
6					✓		✓	✓	✓	✓
7						✓	✓			✓
8						✓	✓	✓	✓	✓
9-16	As 1 - 8 but excluding Index of industrial production									
16-24	As 9 - 16 but only covering the period 1964 - 1976									

Model selection was based on the following statistical tests:

1) As high an r^2 value as possible (Appendix 1)
2) t-tests for the regression coefficients should lie in the range ±2 (Appendix 1)
3) The regression coefficient for lagged demand should lie in the range 0-1 (Section 7.3.2).
4) The coefficient of stock changes, lagged by one year, should be minus the product of the coefficients of current stock changes and lagged demand (Section 7.3.1).

Additional selection was based on a subjective assessment of the plausability of a model covering such aspects as ensuring that the sign of a coefficient agreed with the prior economic analysis.

7.4.2 Model Results - Unalloyed Semis Consumption

The results of the models proposed in Table 7.3 are given in Table 7.4.

Applying the statistical criteria given in Section 7.4.1, all of the eight models which included the index of industrial production may be eliminated except for Models 4 and 8. For these two models, the r^2 values are similar (0.914 and 0.880 respectively); the sign of the regression coefficient are as expected and in both models the t-tests for all the variables are significant except those for lagged stock changes. The final criteria i.e. that the coefficient of the lagged stock changes should be minus the product of the coefficients of the lagged dependent variable and current stock changes, is not satisfied by either model. In Model 4 the calculated value is -0.0952 compared to a model value of -0.0079 and in Model 8 the values are -0.0911 and -0.0501 respectively. This may be due to the low t-test for the lagged stock

Table 7.4 - Model Results - Unalloyed Semi's Consumption

Model Run No.	r^2 value	Real Price of Copper (t)	Real Price of Aluminium (t)	Real Price of Copper (t-1)	Real Price of aluminium (t-1)	Ratio of price AL to price Cu (t)	Ratio of price AL to price Cu (t-1)	Index of industrial production (t)	Deflated material and fuel stock (changes) (t)	Deflated material and stock changes (t-1)	Lagged dependent variable	Constant	Original Model No.
1	0.626	-0.0468 (-0.429)	0.1845 (0.454)					0.1993 (0.243)			0.8100 (4.227)	36.345	
2	0.867	-0.2651 (-3.080)	0.6042 (2.179)					1.0209 (1.745)	0.2081 (4.346)	-0.0988 (-2.328)	1.0401 (7.769)	-127.5	
3	0.833			-0.2469 (-4.346)	0.5544 (2.415)			0.9970 (2.248)			0.8778 (7.766)	59.15	
4	0.914			-0.2476 (-4.728)	0.4636 (2.461)			0.9898 (2.465)	0.1146 (3.652)	0.0079 (0.192)	0.8315 (8.829)	-29.24	
5	0.623					25.496 (0.375)		0.0972 (0.128)			0.8200 (4.286)	43.775	
6	0.873					180.37 (3.397)		1.1717 (2.138)	0.219 (4.724)	-0.1008 (-2.523)	1.005 (8.397)	-251.8	
7	0.805						139.04 (4.019)	0.9382 (2.033)			0.8843 (7.635)	-122.1	
8	0.880						127.90 (3.592)	0.8691 (1.881)	0.1087 (3.044)	-0.0501 (-0.105)	0.8385 (7.921)	-95.95	
9	0.914			-0.2420 (-5.756)	0.4516 (2.628)			0.9485 (2.891)	0.1146 (3.776)		0.8384 (9.953)	-27.5	4
10	0.879						130.06 (4.614)	0.8957 (2.393)	0.1086 (3.141)		0.9523 (8.762)	-98.28	8
11	0.866			-0.1819 (-4.1)	0.2447 (1.3)				0.1181 (3.2)		0.8909 (9.0)	54.21	
12	0.926			-0.2502 (5.3)	0.4278 (2.5)				0.1181 (3.4)		0.7224 (6.9)	119.51	1964-1976 data only

Notes a) upper figure for each criteria = regression coefficient value
b) lower figure for each criteria = t-test value.

changes but it is interesting to note that the calculated values for both models are close. If Models 4 and 8 are re-run but without the lagged stock change variable, model numbers 9 and 10 are obtained. It is apparent that the removal of this variable, while possibly incorrect from an econometric point of view does not significantly affect the r^2 values. In fact Model 9 shows the least change from its initial run (Model 4) and together with its higher r^2 value compared to Model 10, means that it has been selected as the most appropriate model of U.K. unalloyed semis consumption.

The actual and predicted values of unalloyed semis consumption, together with the residuals are presented in Table 7.5 below and are shown graphically in Figure 7.5 later in this section.

Table 7.5 - Actual and Predicted Values of Unalloyed Semis Consumption from Models 9 and 12 in Table 7.4

		Model 9		Model 12	
Year	Actual	Predicted	Residual	Predicted	Residual
1956	291.5	303.2	-11.7	-	-
1957	305.1	290.7	14.3	-	-
1958	316.4	316.1	0.2	-	-
1959	326.1	344.0	-17.9	-	-
1960	373.9	368.6	5.3	-	-
1961	381.1	390.9	-9.8	-	-
1962	376.7	386.9	-10.2	-	-
1963	399.5	390.3	9.1	-	-
1964	467.3	437.3	29.9	450.4	16.9
1965	476.1	463.1	12.9	464.7	11.4
1966	422.4	437.8	-15.4	435.7	-13.3
1967	371.4	372.7	-1.3	375.3	-3.9
1968	375.7	376.4	-0.7	380.9	-5.2
1969	367.5	373.7	-6.2	374.3	-6.8
1970	361.8	356.5	5.2	357.4	4.4
1971	336.6	338.0	-1.4	338.9	-2.3
1972	375.3	355.9	19.4	359.2	16.1
1973	389.1	418.9	-29.8	412.3	-23.2
1974	368.1	361.4	6.6	355.3	12.8
1975	328.7	322.5	6.1	324.0	4.7
1976	350.7	355.2	-4.5	362.3	-11.6

The results from the models which excluded the index of industrial production showed the same basic patterns as those observed in the models discussed above and, for convenience, only the selected models have been listed in Table 7.4.

The lower r^2 value and t-test for the lagged coefficient of the price of aluminium in Model 11 makes this model unattractive. However, Model 12, which covers the period 1964 - 1976 only, has a higher r^2 value (0.926) than Model 9 and also has significant t-tests for all variables. The results obtained from Model 12 are also given in Table 7.5. The similarity of the predicted values from Models 9 and 12 would complicate Figure 7.6 and so only the results from Model 9 have been shown.

7.4.3 Model Results - Alloyed Semis Consumption

The results of the eight models proposed in Table 7.3 for alloyed semis consumption are presented in Table 7.6.

Models 1, 3, 5 and 7 may be eliminated immediately using the statistical criteria given in Section 7.4.1.

The long term stable trend in alloy semis consumption, identified in Chapter 5, means that the remaining models all of which include an upward moving industrial production index have low t-tests for this variable. If the variables with low t-tests (remembering the effects of multi-collinearity) are removed until all t-tests are significant then Models 9, 10, 11 and 12 are obtained.

Model 12 was selected (using the critieria given in Section 7.4.1) as the model for alloyed semis cons. No check on the coefficient of lagged stock changes could be made as this was not included in the model.

The actual and predicted values of U.K. alloy semis consumption using Model 12 are presented in Table 7.7 and graphically in Figure 7.6.

Table 7.6 - Model Results - Alloyed Semi's Consumption

Model Run No.	R^2 value	Real Price of Copper (t)	Real Price of Aluminium (t)	Real Price of Copper (t-1)	Real Price of aluminium (t-1)	Ratio of price AL to price Cu (t)	Ratio of price AL to price Cu (t-1)	Index of industrial production (t)	Deflated material and fuel stock (changes) (t)	Deflated material and stock changes (t-1)	Lagged dependent variable	Constant	Original Model No.
1	0.471	0.1381 (1.964)	0.0082 (0.030)					-1.049 (-1.710)			0.1710 (0.708)	240.24	
2	0.849	-0.0295 (-0.595)	0.2832 (1.658)					-0.0338 (-0.083)	0.1652 (5.827)	-0.0328 (-0.728)	0.4173 (1.598)	93.117	
3	0.443			-1.004 (-1.467)	0.4050 (1.710)			0.3903 (0.709)			0.6085 (2.388)	15.609	
4	0.870			-0.0737 (-1.993)	0.2505 (1.782)			-0.0927 (0.321)	0.1485 (6.661)	-0.0143 (-0.338)	0.5076 (2.402)	80.354	
5	0.472					-106.0 (-2.361)		-1.563 (-2.411)			0.1709 (0.734)	396.1	
6	0.823					21.255 (0.574)		-0.293 (-0.056)	0.1628 (5.344)	-0.0671 (-1.497)	0.6586 (2.515)	64.406	
7	0.464						89.289 (2.293)	0.6979 (1.248)			0.7969 (3.319)	-70.76	
8	0.874						54.007 (2.538)	0.2547 (0.854)	0.1436 (6.703)	-0.0345 (-0.951)	0.6786 (3.734)	14.357	
9	0.843	-0.0352 (-1.294)	0.3525 (2.894)						0.1704 (6.894)		0.2767 (2.322)	111.7	2
10	0.786					28.518 (1.657)			0.1732 (6.278)		0.4236 (3.677)	110.29	6
11	0.861						46.575 (3.650)		0.1502 (7.380)		0.4897 (5.178)	84.718	8
12	0.868			-0.0694 (-2.987)	0.2617 (2.348)				0.1505 (7.311)		0.4287 (4.229)	103.31	4

Notes a) upper figure for each criteria - regression coefficient value
b) lower figure for each criteria - t-test value.

FIGURE 7.6 - ACTUAL AND PREDICTED VALUES OF UNALLOYED AND ALLOYED SEMI'S CONSUMPTION. (FROM TABLES 7.5 AND 7.7)

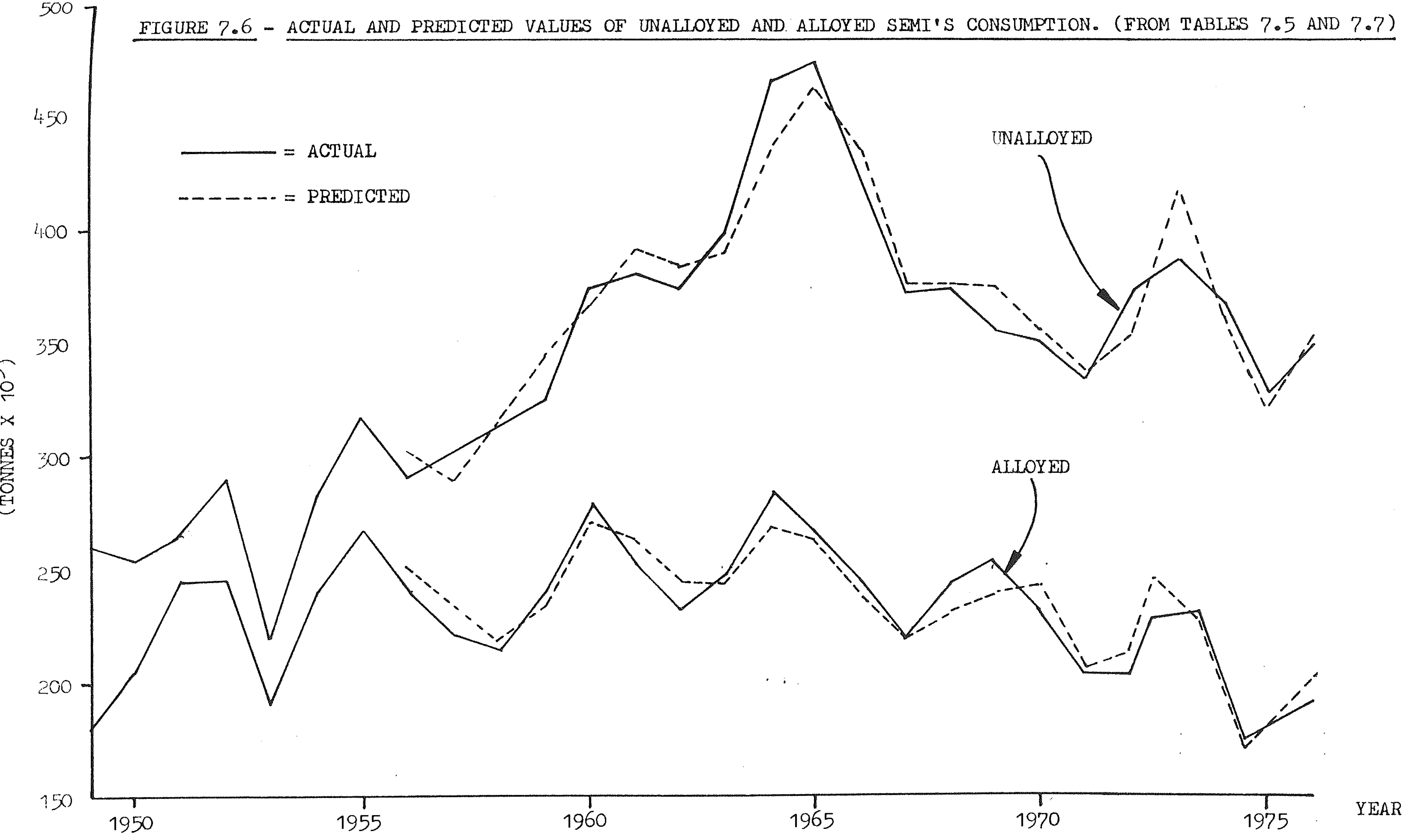


Table 7.7 - Actual and Predicted Values of U.K. Alloyed Semis Consumption using Model 12 in Table 7.6

Year	Actual	Predicted	Residual
1956	239.9	252.4	-12.5
1957	222.9	235.0	-12.1
1958	215.7	219.0	-3.3
1959	240.7	234.1	6.6
1960	278.6	271.8	6.8
1961	252.4	263.6	-11.2
1962	232.2	234.2	-2.0
1963	247.1	234.8	12.3
1964	279.5	269.4	10.1
1965	269.6	263.6	6.0
1966	246.2	239.9	6.3
1967	219.8	220.5	-0.7
1968	243.7	231.4	12.3
1969	255.0	239.7	15.3
1970	233.1	244.8	-11.7
1971	206.9	207.1	-0.2
1972	206.6	215.1	-8.5
1973	228.4	247.3	-18.9
1974	232.7	229.1	3.6
1975	175.2	171.7	3.5
1976	192.9	194.6	-1.7

7.4.4 Model Results - Total Semis Consumption

The results of the models proposed in Table 7.3 for the aggregate demand for copper goods are given in Table 7.8.

All models except 4 and 8 may be eliminated using the criteria given in Section 7.4.1. Models 4 and 8 are very similar, differing only in the measure of copper and aluminium prices and in both models the t-test for lagged stock changes is insignificant at the 95% level. Applying the statistical criterion of the coefficient of lagged stock changes being minus the product of the coefficients of lagged demand and current stock changes, the calculated and actual values for Model 4 were -0.2116 and -0.0543 respectively and for Model 8, -0.2097 and -0.0666. As in the case of demand for unalloyed semis, if the lagged stock changes variable is removed, Models 9 and 10 are obtained where all t-tests are significant. The higher r^2 value for Model 9 resulted in its selection as the best industrial production dependent model for the total consumption of semi-manufactures. The actual and predicted values are given in Table 7.9 and presented graphically in Figure 7.7.

As in the case of unalloyed semis consumption, only the selected industrial production independent models of total semis consumption have been listed in Table 7.8. As in Section 7.4.2 the industrial production independent model (Model 11) for the whole period is less accurate than Model 9. The same model for the period 1964 - 1976 only (Model 12), has a higher r^2 value and complies well with the expected break from industrial production since 1964. The predicted values using Model 12 in Table 7.8 are shown in Table 7.9. Although statistically more significant than Model 9, the predicted results are similar to those from Model 9 and so have not been reproduced in Figure 7.7.

Table 7.9 - Actual and Predicted Values of U.K. Total Semis Consumption using Models 9 and 12 in Table 7.8

Year	Actual	Model 9		Model 12	
		Predicted	Residual	Predicted	Residual
1956	531.4	558.2	-26.8	-	-
1957	528.0	520.8	7.1	-	-
1958	532.1	529.1	2.9	-	-
1959	566.8	570.2	-3.4	-	-
1960	652.5	639.8	12.6	-	-
1961	633.5	665.5	-32.0	-	-
1962	608.9	624.7	-15.8	-	-
1963	646.5	622.3	24.2	-	-
1964	746.8	710.3	36.4	726.4	20.4
1965	745.6	734.6	11.0	740.7	5.0
1966	668.6	678.0	-9.4	683.0	-14.4
1967	591.2	586.3	4.8	596.6	-5.4
1968	619.4	603.2	16.1	608.8	10.6
1969	622.5	615.7	6.7	614.7	7.8
1970	594.9	604.9	-10.0	604.2	-9.3
1971	543.5	545.1	-1.6	544.4	-0.9
1972	581.9	570.2	11.6	568.9	13.0
1973	617.4	666.4	-48.9	654.3	-36.8
1974	600.8	586.6	14.1	583.5	17.5
1975	503.9	501.8	2.0	504.0	-0.1
1976	543.5	545.1	-1.5	550.9	-7.3

Table 7.8 - Model Results - Total Semis Consumption

Model No.	R^2 value	Real Price of Copper (t)	Real Price of Aluminium (t)	Real Price of Copper (t-1)	Real Price of Aluminium (t-1)	Ratio of price Al to price Cu (t)	Ratio of price Al to price Cu (t-1)	Index of industrial production (t)	Deflated material and fuel stock changes (t)	Deflated material and stock changes (t-1)	Lagged Dependent variable	Constant	Original Model No.
1	0.475	0.0979 (0.534)	0.0881 (2.004)					-0.3931 (-0.282)			6.0000 (2.623)	227.63	
2	0.866	-0.3325 (-2.726)	0.7755 (2.004)					1.4453 (1.726)	0.3721 (5.534)	-0.2172 (-3.154)	1.0189 (6.586)	174.9	
3	0.706			-0.3809 (-3.430)	0.9461 (2.209)			1.7175 (2.124)			0.8541 (5.525)	-109.0	
4	0.917			-0.3286 (-4.523)	0.6340 (2.389)			1.2801 (2.426)	0.2565 (5.866)	-0.0543 (-0.863)	0.8251 (7.819)	-20.71	
5	0.472					-79.400 (-0.680)		-0.8697 (-0.636)			0.6000 (2.626)	365.41	
6	0.879					249.51 (3.264)		1.8669 (2.285)	0.3938 (6.180)	-0.2382 (-3.760)	1.1317 (7.607)	-402.0	
7	0.708						239.68 (3.822)	1.7830 (2.252)			0.9034 (6.201)	-245.1	
8	0.905						186.67 (4.178)	1.2539 (2.281)	0.2457 (5.437)	-0.0666 (-1.036)	0.8536 (8.133)	176.3	
9	0.913			-0.3595 (-5.733)	0.7189 (2.942)			1.5012 (3.283)	0.2577 (5.947)		0.7760 (8.807)	-17.78	4
10	0.898						210.05 (5.433)	1.5230 (3.137)	0.2465 (5.443)		0.7900 (8.783)	-149.4	8
11	0.850			-0.2429 (-3.7)	0.3947 (1.4)				0.2690 (4.9)		0.7515 (6.7)	14.91	
12	0.955			-0.3425 (-5.8)	0.6166 (2.9)				0.2626 (6.1)		0.7047 (8.1)	187.96	1964-1976 data only

Notes: As Table 7.4

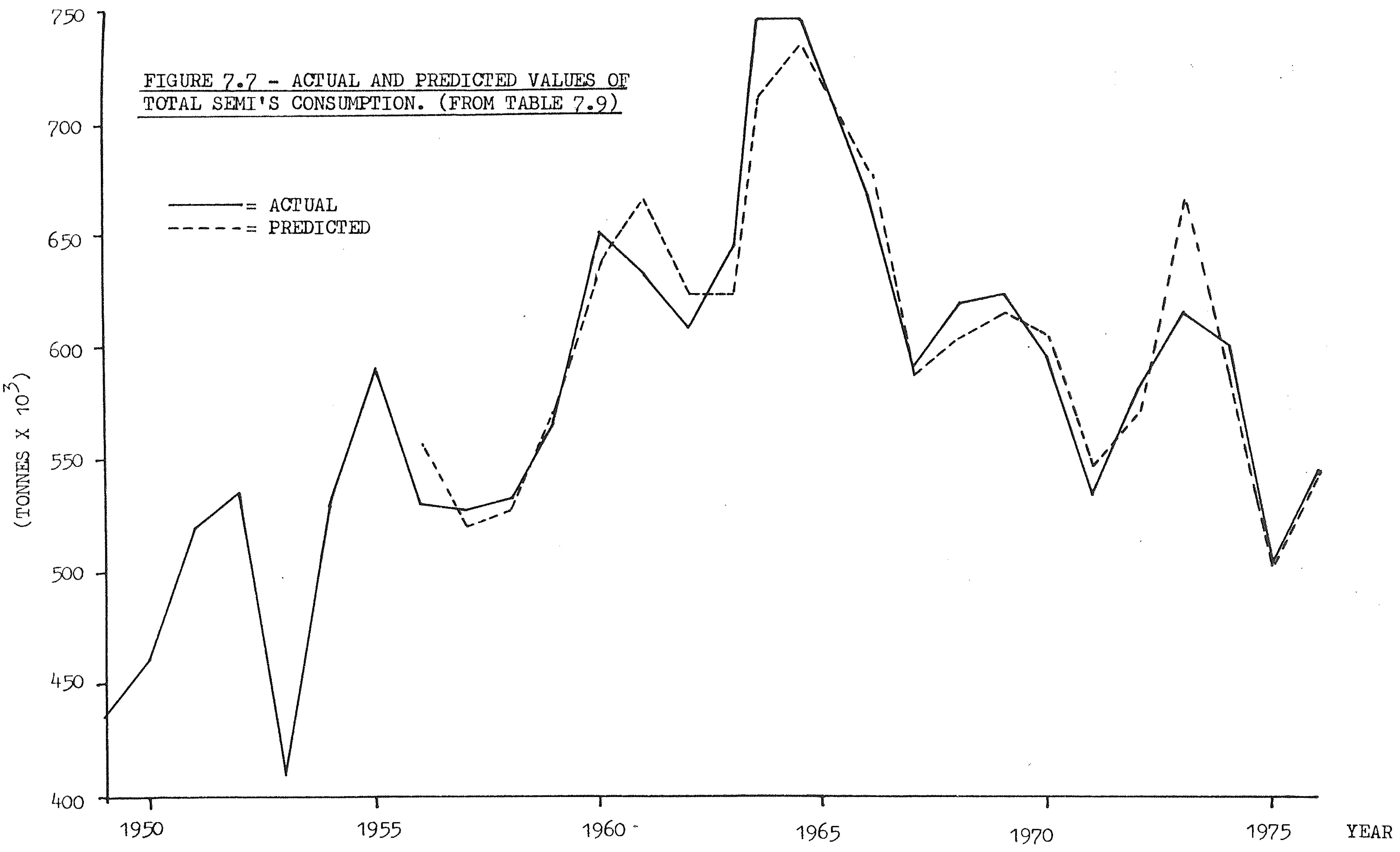


FIGURE 7.7 - ACTUAL AND PREDICTED VALUES OF TOTAL SEMI'S CONSUMPTION. (FROM TABLE 7.9)

7.4.5 Discussion of Model Results

The five models of total, unalloyed and alloyed semis consumption selected in the previous sections are given below:

$$\begin{array}{l}\text{Total}\\ \text{semis}\\ \text{cons,t}\end{array} = -17.78 + 0.7760 \boxed{\begin{array}{c}\text{Total}\\ \text{semis cons.}\\ \text{t-1}\end{array}} - 0.3595 \boxed{\begin{array}{c}\text{Real price}\\ \text{of copper}\\ \text{t-1}\end{array}} + 0.7189$$

$$\boxed{\begin{array}{c}\text{Real price}\\ \text{of aluminium}\\ \text{t-1}\end{array}} + 1.5012 \boxed{\begin{array}{c}\text{Index of}\\ \text{industrial}\\ \text{production,t,}\end{array}} + 0.2577 \boxed{\begin{array}{l}\text{Deflated}\\ \text{materials \&}\\ \text{fuel stock}\\ \text{changes, t}\end{array}}$$

$$\text{or} \quad = 187.96 + 0.7047 \boxed{\begin{array}{c}\text{Total}\\ \text{semis cons.}\\ \text{t-1}\end{array}} -0.3425 \boxed{\begin{array}{c}\text{Real price}\\ \text{of copper}\\ \text{t-1}\end{array}}$$

$$+ 0.6166 \boxed{\begin{array}{c}\text{Real price}\\ \text{of aluminium,}\\ \text{t-1}\end{array}} + \ldots + 0.2626 \boxed{\begin{array}{c}\text{Deflated}\\ \text{materials \&}\\ \text{fuel stock}\\ \text{changes, t}\end{array}} \quad \begin{array}{c}\text{(1964-76}\\ \text{only)}\end{array}$$

$$\begin{array}{l}\text{Unalloyed}\\ \text{semis}\\ \text{cons, (t)}\end{array} = -27.5 + 0.8384 \boxed{\begin{array}{c}\text{Unalloyed}\\ \text{semis cons,}\\ \text{t-1}\end{array}} - 0.2420 \boxed{\begin{array}{c}\text{Real price}\\ \text{of copper}\\ \text{t-1}\end{array}} + 0.4516$$

$$\boxed{\begin{array}{c}\text{Real price}\\ \text{of aluminium}\\ \text{t-1}\end{array}} + 0.9485 \boxed{\begin{array}{c}\text{Index of}\\ \text{industrial}\\ \text{production,}\\ \text{t,}\end{array}} + 0.1146 \boxed{\begin{array}{c}\text{Deflated}\\ \text{materials \&}\\ \text{fuel stock}\\ \text{changes, t,}\end{array}}$$

$$\text{or} \quad = 119.51 + 0.7224 \boxed{\begin{array}{c}\text{Unalloyed}\\ \text{semis cons,}\\ \text{t-1}\end{array}} - 0.2502 \boxed{\begin{array}{c}\text{Real price}\\ \text{of copper}\\ \text{t-1}\end{array}}$$

$$+ 0.4278 \boxed{\begin{array}{c}\text{Real price}\\ \text{of aluminium,}\\ \text{t-1}\end{array}} + \ldots + 1181 \boxed{\begin{array}{c}\text{Deflated}\\ \text{materials \&}\\ \text{fuel stock}\\ \text{changes, t,}\end{array}} \quad \begin{array}{c}\text{(1964-76}\\ \text{only)}\end{array}$$

$$\begin{array}{l}\text{Alloyed}\\ \text{semis}\\ \text{cons, (t)}\end{array} = 103.31 + 0.4287 \boxed{\begin{array}{c}\text{Alloyed}\\ \text{semis cons,}\\ \text{t-1,}\end{array}} -0.0694 \boxed{\begin{array}{c}\text{Real price}\\ \text{of copper}\\ \text{t-1}\end{array}} + 0.2617$$

$$\boxed{\begin{array}{c}\text{Real}\\ \text{price of}\\ \text{aluminium}\\ \text{t-1}\end{array}} + \ldots\ldots + 0.1505 \boxed{\begin{array}{c}\text{Deflated}\\ \text{materials \&}\\ \text{fuel stock}\\ \text{changes, t,}\end{array}}$$

Current price variables were found not to be as accurate in predicting demand as lagged prices, so supporting the adaptive expectations model put forward in section 7.3.2. Further support is found by examining the regression coefficients for lagged demand where, for total and unalloyed semis consumption values of 0.7760 and 0.8384 were determined for the industrial production dependent models. This coefficient is equal to $1-\mu$ where μ is the speed of adjustment factor and indicates the fraction of the difference between desired and actual demand closed each year. In the cases above, the values of μ are 0.2240 and 0.1616 indicating that only a small fraction of the gap was closed, resulting in a large difference between the long-run and short run demand elasticities. The industrial production independent models for the period 1964 - 1976 have μ values of 0.2953 and 0.2776 respectively, these slightly higher values indicate that long-run and short-run demand is being balanced more easily over this period. In the case of alloyed semis demand, the index of industrial production, a measure of the activity level, is missing, reflecting the stable nature of this market. The speed of adjustment factor, μ, for alloyed semis consumption is 0.5713 and illustrates the ability of the alloy semi-manufacturers to respond to price changes by increasing or decreasing their use of scrap.

Lags greater than one year were not found in any of the models produced and it must be concluded that the model quoted by Gluschke (93) did not investigate the effects of lags other than the seve year business cycle lag used.

The above models are statistically and economically sound according to the criteria laid down in earlier sections and both industrial production dependent and independent models will be used in Chapter 10 to forecast future demand for copper goods.

7.5 Summary to Chapter 7

U.K. demand for copper goods, broken down into total, unalloyed and alloyed semis consumption has been successfully modelled. No other models of U.K. demand for copper goods have been found but the models obtained agree with both economic theory and models produced for other countries and are suitable for forecasting future demand.

Factors affecting demand were discussed prior to modelling and those found to be relevant were the prices of copper and aluminium lagged by one year, lagged demand and material and fuel stock changes. The contribution of industrial production was found to be small over the period 1964 - 1976 and evidence of a break away from the historical link identified earlier obtained.

Evidence was found for the adaptive expectations model of commodity demand with alloyed semis demand being more responsive to price changes than unalloyed semis demand.

The methodology developed in this chapter will now be applied to copper scrap flows in Chapter 8 and 9 and projections into the future made in Chapter 10, after which the effect of policy changes will be investigated.

CHAPTER 8 MODELLING THE U.K. SUPPLY OF COPPER SCRAP

8.1 Introduction

In previous chapters the background to modelling the supply and demand for copper scrap has been presented. In this chapter and chapter 9 the elements discussed in these earlier chapters will be joined together to describe and model the factors affecting the supply and demand for copper scrap.

8.2 Measures of the U.K. Supply of Copper Scrap

The supply of scrap provides an important measure of the availability of scrap for recycling and in particular, an upper limit to the available. The supply of scrap may be defined at various points in the copper industry. Figure 8.1 represents a generalisation of the copper scrap system abstracted from Figure 5.1.

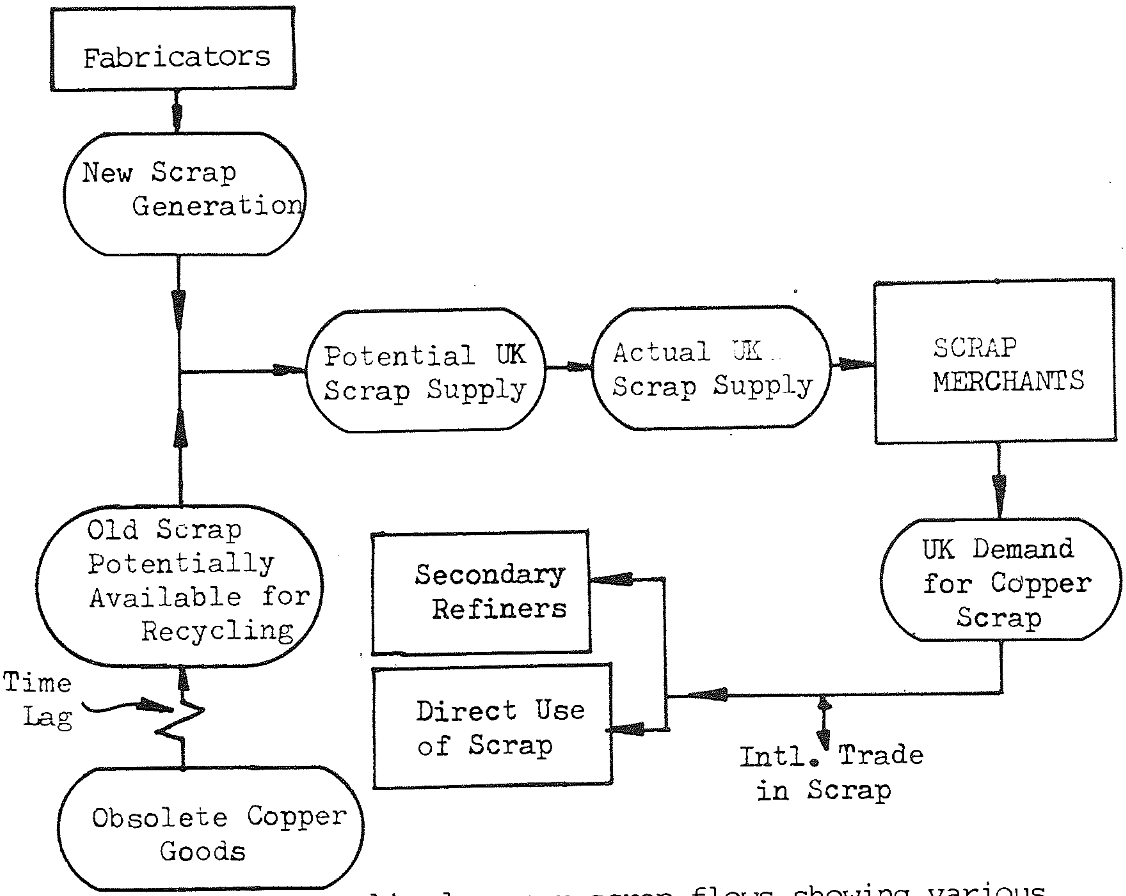


Figure 8.1 - Generalised copper scrap flows showing various measures of scrap supply (abstracted from Fig. 5.1)

The complexity of the scrap flows in Figure 8.1 and, in particular, the lack of data on the interaction of the scrap supply and demand sectors, makes accurate measurement of actual scrap supply impractical. In this work the term scrap supply applies to the size of the flow of copper scrap from its point of generation to the scrap merchants and the term scrap demand to refer to the size of scrap flows from the scrap merchants to the scrap users. Lack of available data, as discussed in Chapter 5, limits measurement of the flows in Figure 8.1 to the U.K. potential supply of copper scrap, and even this is a calculated, not measured value. This limits this section to a qualitative discussion on the factors affecting scrap recovery from old and new scrap. A model of the potential supply of scrap for recycling will also be developed. In Chapter 9, the factors affecting how much copper scrap is actually demanded, i.e. recycled, will be discussed.

For convenience the following discussion will consider new and old scrap supply separately.

8.3 The Supply of New Scrap

Generally, new scrap arising from the fabricating processes is clean and well segregated and therefore has a high value. The fact that new scrap is produced at the fabricators means that it is relatively concentrated and easily recovered. All these factors combine to ensure the fast recovery and reuse of new scrap.

Unfortunately, available U.K. statistics do not distinguish between annual new and old scrap supply (see section 5.3.5) and no definitive work on the breakdown of annual total scrap use into new and old scrap has been found, although various estimates for the U.K. have been put forward. An International Wrought Copper Council (IWCC) report

(86) estimated a ratio of 85:15 of annual total scrap use for new and old scrap respectively, while Alexander and Appoo (88), suspecting this ratio to be inaccurate, consulted several copper refiners and concluded that the ratio was 50:50. Tron (107) developed a more complicated method (which was adopted in Chapter 5); the inaccuracy of using a single ratio is that not all fabricating processes have the same efficiency and changes in demand for the various fabricated products would not be included. By using average fabricating efficiencies abstracted from Dyson (108) and production data for each fabricated shape group, Tron estimated the new scrap generated. This method as previously stated, takes into account the changes in demand for various shape groups and Tron found that over the period 1946-1973 new scrap generation rose by 50%, while fabricated goods production rose by 67% and attributed this trend to the expansion of the electrical and construction industries with the resultant heavy demand for copper wire and tubes. If this trend continues with technological progress then new scrap availability will decrease in future years. While a useful step forward in developing comprehensive data on scrap, Tron's work does not take into account technological changes, although it is fair to say that greater errors are introduced elsewhere, for example, in the estimation of the direct use of scrap.

In the U.S., scrap statistics are much more developed and distinguish between new and old scrap consumption by the semi-manufacturers. If it is assumed that technological change in the U.S. is paralleled in the U.K., then it may be possible to analyse U.S. fabricated shape group production and new scrap consumption and estimate both fabrication efficiencies and how these efficiencies have changed. This data could then be applied to U.K. statistics.

New scrap supply is generally conceded to be price inelastic, certainly this is the case in respect of the U.K. estimates presented above. Anderson (134) considered that, in the U.S., this was due to the fact that new scrap flows from the point of generation to the market place regardless of market conditions and that fabricators generally do not have the space to store generated new scrap for speculation purposes. Anderson related the volume of new scrap generated only to production technology, product mix and production volume and this view is also adopted by Gordon (135). Increases or decreases in the price of new scrap do not generally cause corresponding increases or decreases in the volume of new scrap generated. In the long term Gordon considered that low new scrap prices could reduce the use of a metal by a manufacturer although this seems to ignore the link between scrap and refined prices found in section 6.3.5, where low refined prices would promote the use of a metal, not reduce it. A Charles River Associates (131) model investigated the effects of scrap prices upon new scrap supply. The model constructed showed little evidence to support or disprove the view that fabricators would decrease new scrap generation when scrap prices were high.

The structure of the copper industry plays an important role in the response of new scrap supply to price. In a highly vertically integrated copper industry, new scrap would flow within the industry and would not appear on the outside market and would be highly price inelastic. In a copper industry with little vertical integration, large volumes of new scrap would flow through scrap merchants and might be stored in anticipation of higher scrap prices i.e. would be price elastic (see section 4.4.7 and 9.3.2). In such a situation, scrap merchants would probably be under contract to buy scrap or lose the contract and scrap stocks held by the merchant would increase at times of low price. The highly vertically integrated nature of the U.K. copper industry shown in Chapter 4 suggests that little new scrap appears on the outside market with the big three, Delta, IMI and BICC, recirculating the major proportion of new scrap generated internally.

The above discussion supports previous discussions in Chapters 4, 5 and 6 and indicates that new scrap supply, due to data limitations, must be considered as a function of the production of various shape groups and, in the UK, as being price inelastic. In the following analysis it has been assumed that the high value and concentrated nature of new scrap results in its flowing within one year from the fabricators to the scrap consumers.

8.4 The Supply of Old Scrap

8.4.1 The Effect of Price Upon Old Scrap Supply

Old scrap may be a low value, contaminated scrap located in small volumes at widely separate locations. Some clean and segregated old scrap however, will compete directly with new scrap.

While new scrap was found to be generally price inelastic, opinion on the price elasticity of old scrap is divided. Barbour (136) is emphatic that supply of old scrap is dependent upon industrial progress and independent of the market price, but concedes that high scrap prices could stimulate short lived increases in old scrap supply. Anderson (134) believes that old scrap is more responsive to price changes than new scrap and that higher prices will result in increased activity by scrap merchants, increased flow of scrap from remote areas and a higher degree of separation of lower scrap grades by merchants.

Anderson felt, as did Barbour, that the limiting factor would be the availability of old scrap. Siebert (137) proposed that only high prices with fixed primary copper supply would induce an increased suply of old scrap and that in a period of high prices and primary copper over capacity, increased copper supplies would be obtained from primary sources.

Not all authors consider the supply of old scrap to be price inelastic. A US Federal Trade Commission (138) thought that increased prices would result in an increased supply of old scrap not only from merchants but also from industry, which might decide to cash in on the scrap value of obsolete or little used facilities. Mining Magazine (120) was in no doubt that a high level of economic activity and high copper prices call forth increased quantities of old scrap, but gave no indication of the time for which the flow could be maintained.

An important factor in the supply of old scrap is the decision to scrap obsolete or little used plant. It is conventional to argue that scrapping decisions are highly price inelastic as the scrap value will be only a small factor in the abandonment decision. Various economic analyses available for estimating the optimum scrapping time are comprehensively reviewed by Gordon (135). He concluded that industrial scrapping decisions are made using the annual cost method where the cost patterns of the alternatives (including scrapping) are investigated and the alternative with the lowest annual cost selected. The general principle of scrapping decisions are shown in Figure 8.2 where it can be seen that the total cost of using a piece of equipment goes through a minimum.

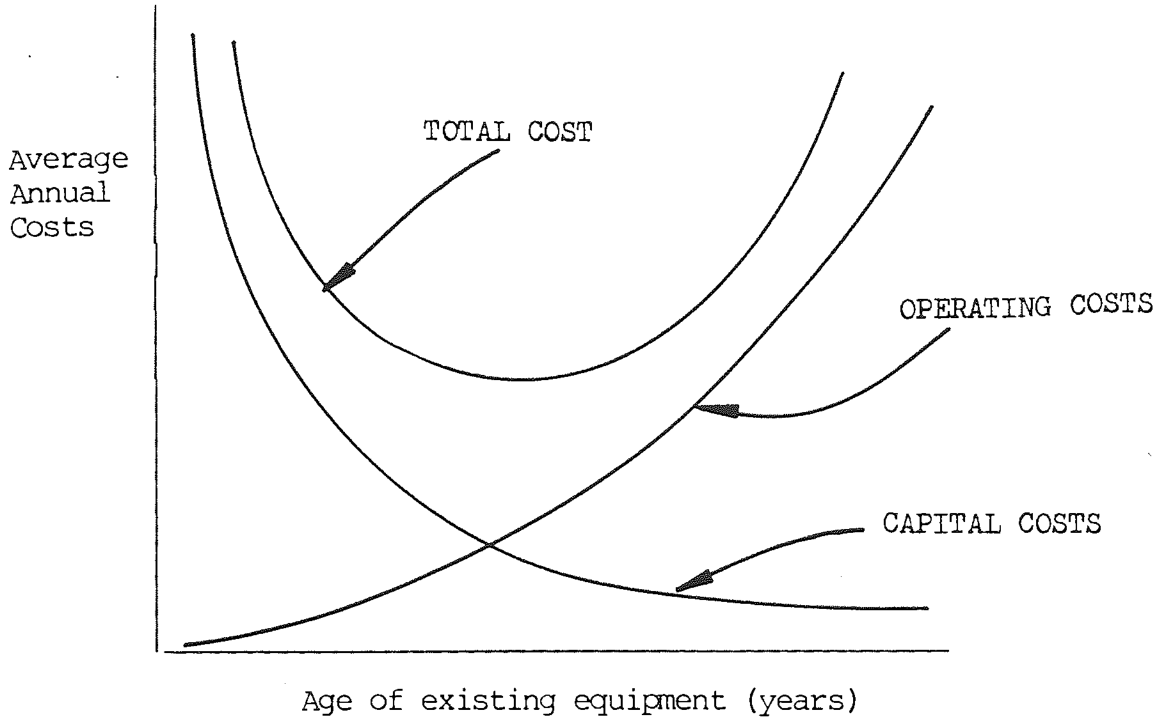


Figure 8.2 - Principle of Scrapping Decisions

As stated earlier, scrapping decisions do not generally depend upon the scrap value of the equipment. In the U.K., a large proportion of copper consumption is in the electrical sector and a major user, the CEGB, does not consider scrap values to be a significant factor in scrapping decisions which are taken on purely technological and repair cost considerations (139).

It must be concluded that old scrap is generally price inelastic but that periods of high prices may influence the scrapping decision to provide a short term increase in old scrap supply. If this conclusion is correct then old scrap supply is a largely automatic process, an opinion shared by Barbour (136), Anderson (134) and Vogely (140) and depends on the volume of old scrap arising in any year.

8.4.2 The Ability of Historic Copper Consumption to Supply Scrap Copper

One of the earliest concepts found in the literature on scrap supplies is that of an accumulating volume of metal embodied in existing products in the economy (Merril (141)). This accummulation is variously referred to as the reservoir, inventory or stock of metal-in-use. Figure 8.3 shows a generalised diagram of the metal-in-use reservoir and its derivation. It can be seen that fabricated products have a useful life during which they contribute to the metal-in-use reservoir until they either wear out and become obsolete, are scrapped and leave the metal-in-use reservoir. The size of the metal-in-use reservoir is a function of the rate at which materials are added to the reservoir i.e. fabricated goods consumption and the rate of withdrawals due to wear and obsolescence. As long as the consumption of scrap is greater than scrap arising the metal-in-use reservoir will grow.

To obtain a more accurate assessment of the reservoir size, dissipative uses should be excluded and have been shown separately in Figure 8.3.

Interest in the extent to which scrap supplies from the metal-in-use reservoir would modify (if at all) future primary metal requirements led to various attempts to determine its size (Merril (141)).

A more intensive study of U.S. obsolete iron and steel was made by the Battelle Memorial Institute in 1957 (142) in order to estimate the metal-in-use reservoir and in addition, the portion which is obsolete and therefore potentially available for reclamation. As the methodology was later utilised by Landsberg in 1963 (143) and a 1972 Battelle study (144) for non-ferrous metals, it will be discussed in some detail. Figure 8.4 shows a schematic representation of the Battelle methodology modified to be consistent with previous diagrams in this work.

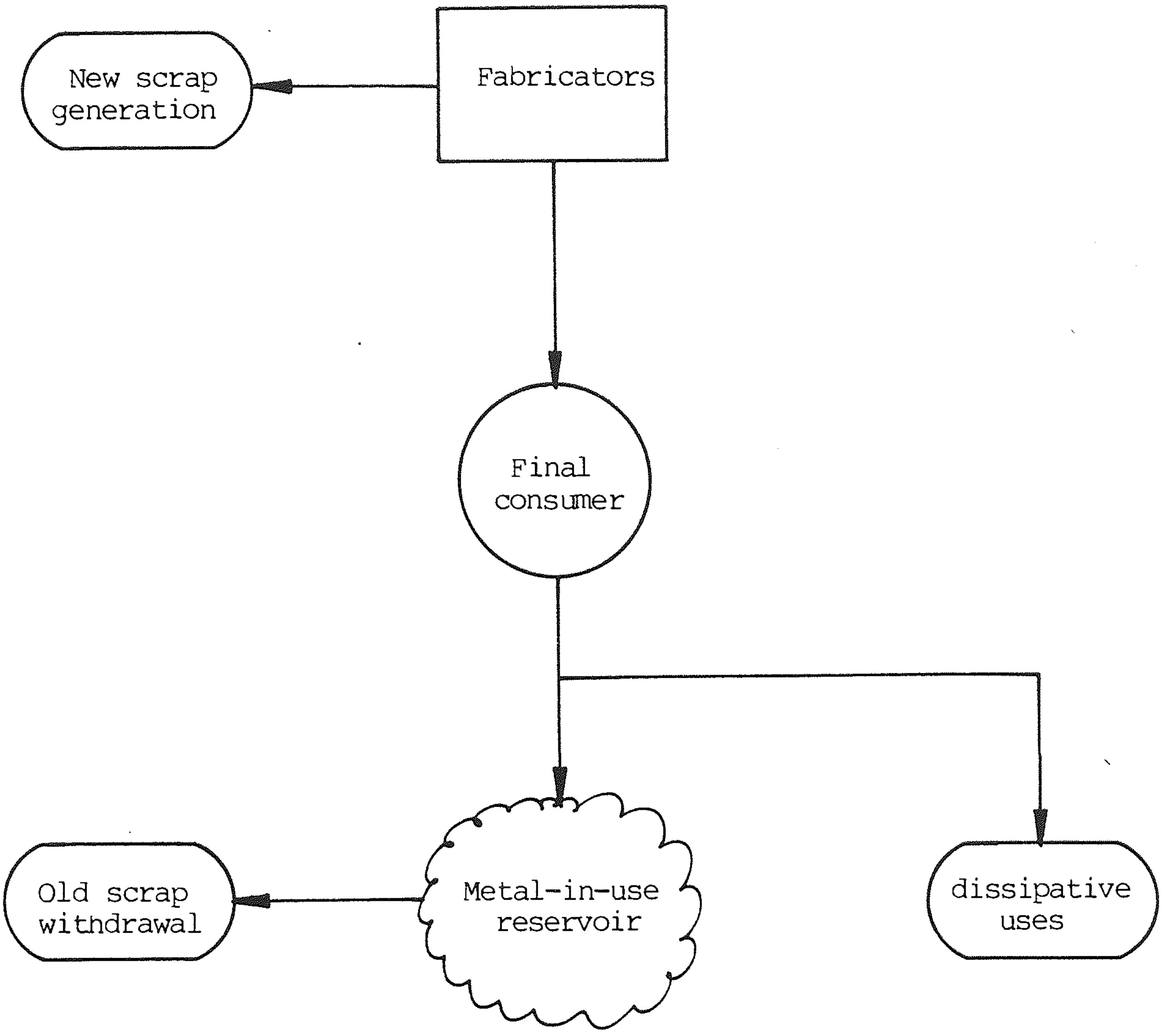


Figure 8.3 - The Metal-in-Use Reservoir

Estimation of the metal-in-use reservoir is achieved by essentially the same method as Merril, but the Battelle method takes an extra step to quantify the obsolete portion of the metal-in-use reservoir on an annual basis, here termed "annual potentially recoverable scrap arisings". This was done by using the important concept of the life cycle of goods contained in the reservoir. The life cycle was defined as the period of time from the production of a product until it has completed its useful life. In this definition is included the time a product is used for its original or primary use, a period of stand-by use when the good is held on standby or for cannibalisation and a period of non-use when the good, although obsolete, has not been sold as scrap. Because of lack of data on secondary uses the Battelle and later studies only considered the primary use period in estimates of life cycles. The Battelle study therefore estimated the quantity of metal becoming obsolete each year from the metal-in-use reservoir by applying suitable life-cycle estimates to historic time-series of consumption of goods.

The Battelle methodology may be realistically improved by considering that the annual crop of potentially recoverable obsolete goods contribute to a pool of similar material. In this case, any years production, after a useful life, may flow into one of three pools listed below and illustrated in Figure 8.5.

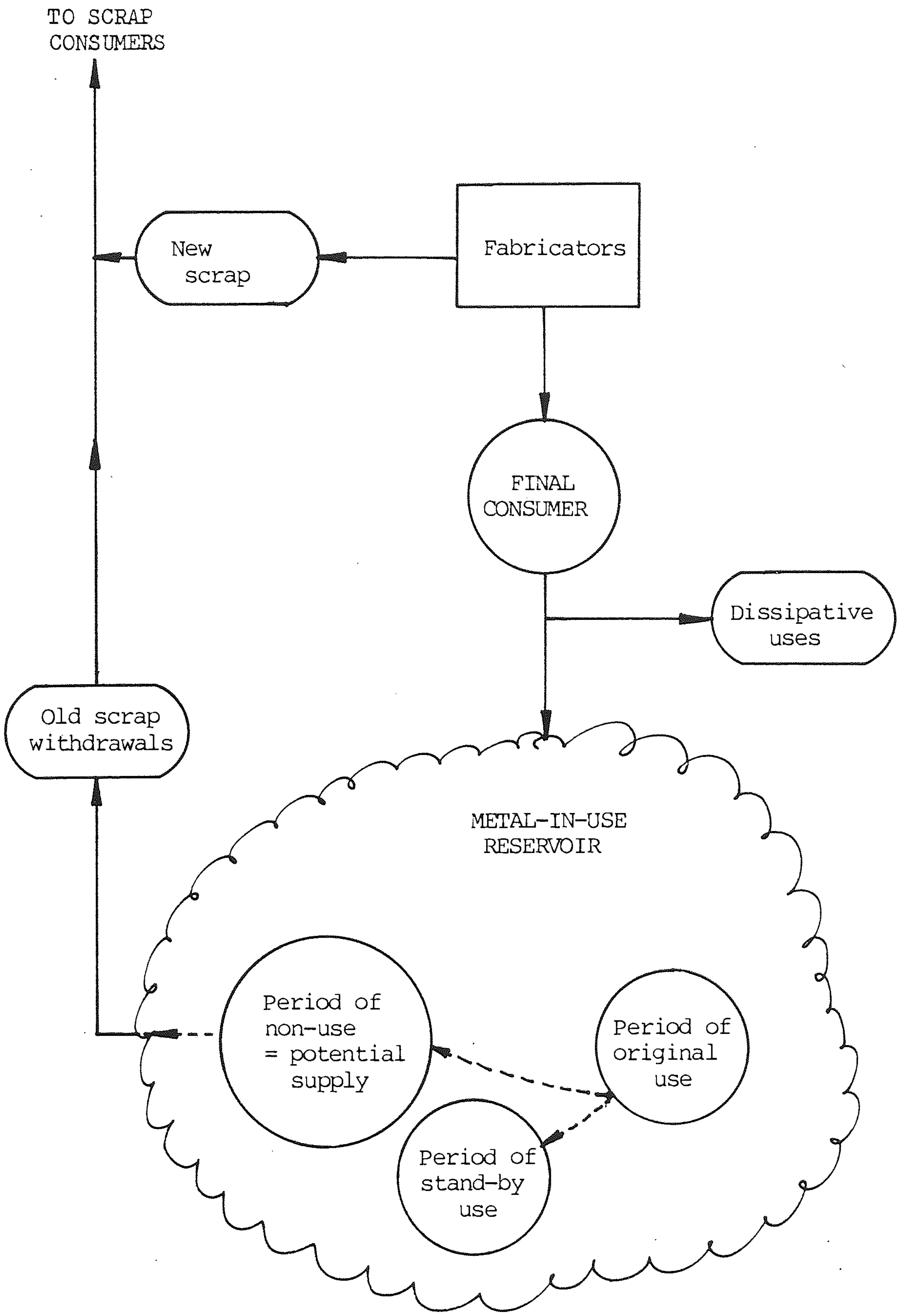


Figure 8.4 - Schematic Diagram of Battelle Study Methodology

Dissipative uses	1) A dissipative pool whose contents will never be reclaimed.
Non-dissiptative uses i.e. with potential for recovery	2) A short-term pool of economically recoverable material; annually supplied by potentially recoverable scrap arisings and which is likely to supply the needs of the secondary copper industry. 3) A semi-permanent pool of potentially recoverable scrap less likely, for economic reasons, to supply the needs of the secondary copper industry.

The second and third pools listed may be grouped together as the pool of potentially recoverable scrap.

Scrap arisings from non-dissipative uses arise on an annual basis from the metal-in-use reservoir and flow into the short-term potentially recoverable scrap pool which probably contains one or two years arisings. Old scrap withdrawals are made from this pool to satisfy demand by the scrap consumers. If demand is low or if the scrap is low grade, some old copper scrap moves to a semi-permanent pool of potentially recoverable old scrap. When old scrap demand is high, this semi-permanent pool may supplement annual potentially recoverable scrap arisings. Alternatively, if old scrap demand is low for a number of years, the semi-permanent pool may become large enough to exert an overriding influence on the old scrap market.

What happens to the old scrap in the semi-permanent pool after a number of years is uncertain, but there is potential for the scrap concerned to move gradually towards the irrecoverable pool of dissipative uses. Generally, however, old scrap withdrawals from annual potentially recoverable scrap arisings occur quickly, probably in less than one year.

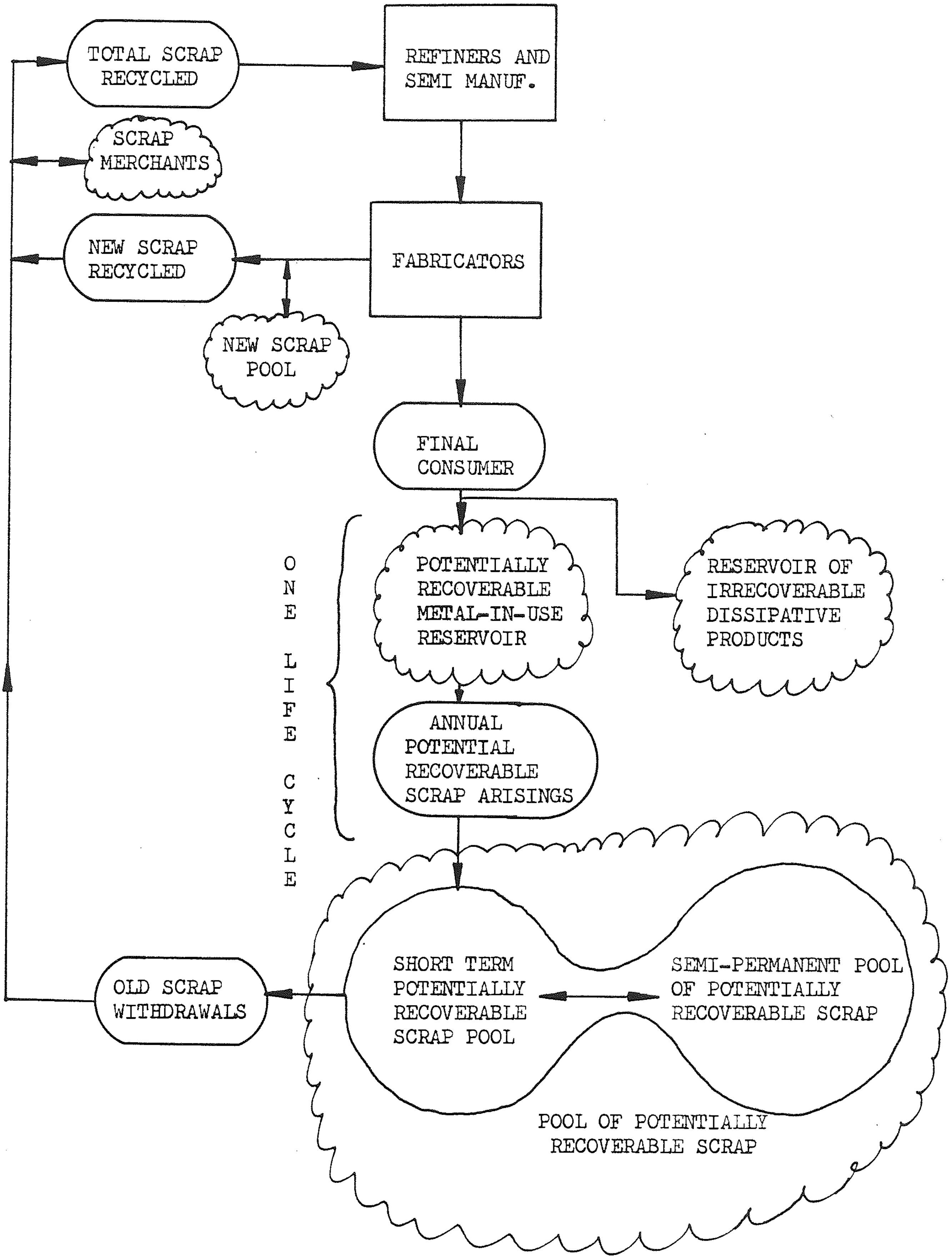


Figure 8.5 - Reservoirs and Pools involved in Scrap Flows

The above analysis shows that the supply of copper scrap may be measured in two useful ways. Firstly, the annual potentially recoverable scrap arisings provide an assessment of the ability of short-term scrap supplies to meet scrap demand by the consuming industries. The quantities involved may be determined by applying life-time estimates to historic consumption of final goods and this will be done in the next section. Secondly, once the annual potentially recoverable scrap arisings have been determined it is possible to estimate the size of the pool of potentially recoverable scrap (i.e. short-term potentially recoverable scrap pool + semi-permanent pool of potentially recoverable scrap). Any increases in recycling activity would probably draw on this pool for scrap supplies and it is therefore important to assess its size. This will be done after the annual potentially recoverable scrap arisings have been calculated.

In order to cross check the results obtained, reference will be made to other published estimates.

8.5 Modelling Annual Potentially Recoverable Scrap Arisings

8.5.1 Introduction

The estimation of annual potentially recoverable scrap arisings (hereafter referred to as "scrap arisings") enables the relationship between scrap arisings and scrap withdrawals (Figure 8.5) to be examined. Additionally,by summing scrap arisings and deducing scrap withdrawals over the entire period, the size of the pool of potentially recoverable scrap may be estimated. The estimation of scrap arisings is a complex problem and most published figures are only very rough estimates.

In order to obtain realistic estimates of annual copper scrap arisings for the U.K, the methodology adopted in Figure 8.6 was used.

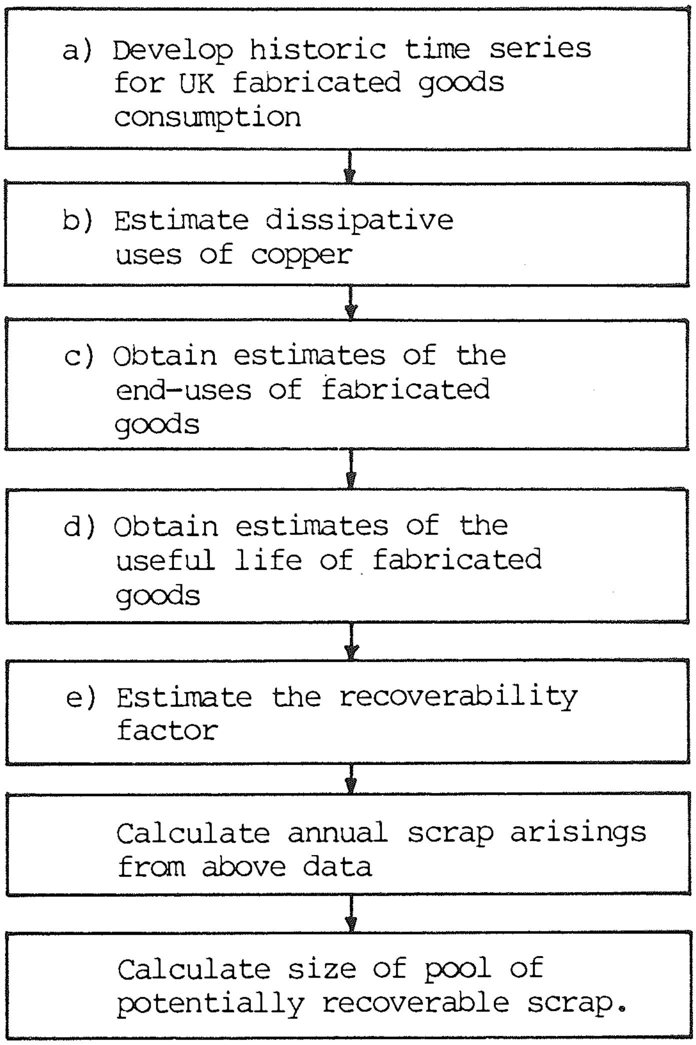


Figure 8.6 - Method of Calculating Annual Potentially Recoverable Scrap Supplies

8.5.2 Development of a Historic Time Series for U.K. Fabricated Goods Consumption

The first step, development of a historic time series for U.K. fabricated goods consumption or final consumption of copper goods has already been carried out in Chapter 5. (See Table 5.14 and Sections 5.3.4, 5.4 and 5.5).

8.5.3 Estimates of the Dissipative Uses of Copper

Few estimates of the dissipative uses of copper are available but are generally considered to be low (88) and mainly in fungicides. A NATO report (24) estimated that 5% of copper consumption was in dissipative uses, mainly in the form of fungicides, industrial uses and laboratory reagents. Another estimate by Bridgwater (145) suggests 1% losses in industrial sludge alone, while Alexander (88) quotes 1% dissipative uses in fungicides and other chemical compounds and assumes total dissipative uses of 3%. Whalley and Broadie (42) estimated that 5% of copper consumption was lost due to corrosion, abrasion and oxidation.

In view of the above estimates, a figure of 5% dissipative uses has been assumed.

8.5.4 End-Uses of Copper

The end-uses of copper have already been described in Section 4.3 and Table 4.5 has been reproduced below. Reference should be made to Section 4.3 for a discussion of the problems affecting end-use measurement.

Table 8.1 - Assumed Breakdown of U.K. Copper Consumption by End-use (from Table 4.5)

End Use	Percentage of Consumption
Electrical	52
Construction	19
General Engineering	15
Transport	12
Domestic Appliances	3

8.5.5 The Life-Cycle of Copper Goods

The most accurate, but most difficult to determine, estimates of life cycles make use of data on the stocks and sales of products, but this is beyond the scope of this project. Other methods of determining life-cycle times have been reviewed by Butlin (146), Smith (147) and Teknekon (148). Several surveys of specific goods have been carried out by Pennock and Jaeger (149), Sawyer (150), Hundy (151) and Chapman (152).

The time needed to construct accurate specific life-cycle estimates has meant that various published lifetime estimates have been examined and a summary table drawn up. It is realised that this method is not as accurate as specific surveys, but it is felt that inaccuracies elsewhere make this the best option available.

Table 8.2 gives various estimates of the lifetime of goods containing copper, broken down by end-uses to suit the data in Table 8.1. Estimates vary widely confirming the uncertainty of data noted above. In order to obtain U.K. estimates, a subjective weighted mean has been taken and is shown in the last column of Table 8.2. Because of intrinsic inaccuracies in Table 8.2, the U.K. estimates have been rounded to the nearest five years.

While it would be useful to determine trends in the lifetimes of copper goods, this is not possible with the available data. End-use breakdowns from Tables 8.1 and 8.2 shows that 70% of annual copper consumption is used by the electrical and construction industries with an average lifetime of 30 years. The remaining 30% is equally divided between lifetimes of 10 and 15 years. The importance of lifetime estimates upon scrap arisings will be investigated later.

Table 8.2 - Various Estimates of the Lifetime of Goods Containing Copper (years)

END-USE	BATTELLE (US) 1972 (144)	CARRILLO (US) 1974 (153)	CHAPMAN (UK) 1975 (152)	STANFORD (US) 1975 (154)	ALEXANDER AND APPOO (UK) 1976 (88)	AUTHORS BASIS
Domestic Appliances		4,7,9	10,45	5	3	10
Electrical	10,45	19,24	(10,15)30	10,15,20,30	51	30
General Engineering	0.5	18	10,15,30	10,60	12	15
Transport	3.5,12	9	10(45)	10	11	10
Construction		19,24,29	10(45)	30	19	30
Other	14,30		15		4	15

Figures in brackets indicate that the lifetimes included are for a small percentage of consumption.

Table 8.3 - Summary of End-use and Lifetime Estimates to be Adopted in Scrap Pool Estimation

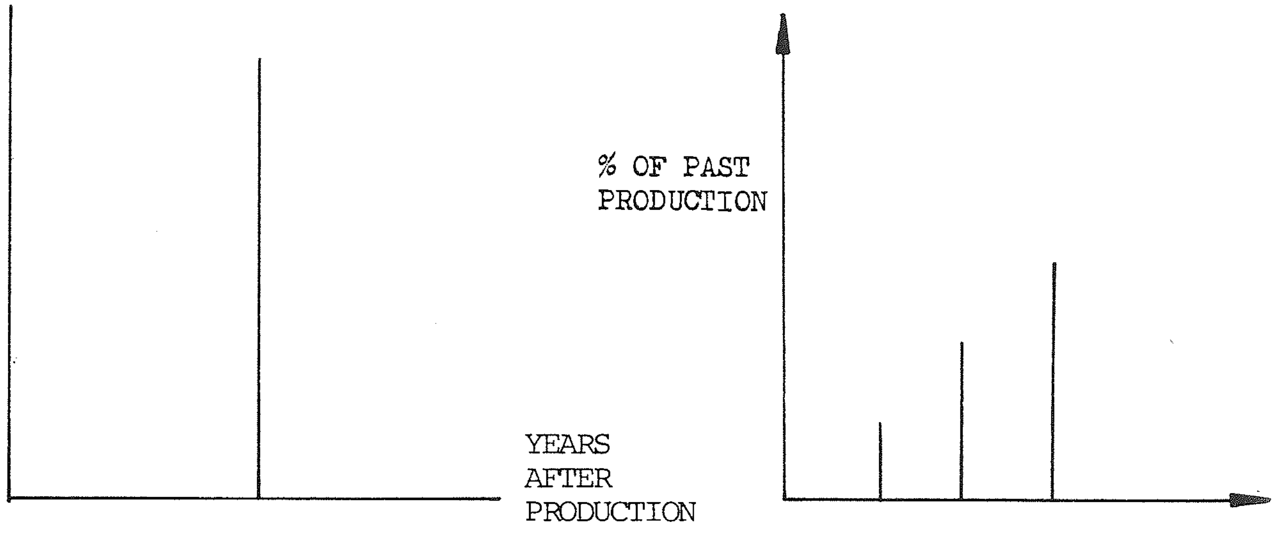
(from Tables 8.1 and 8.2)

End-use	Percentage of annual copper consumption		Average lifetime (years)
Domestic Appliances	3	15	10
Transport	12		
General Engineering	15		15
Electrical	52	70	30
Construction	18		

The type of lifetime distribution assumed is also important in determining annual scrap arisings. Figure 8.7 shows some of the various types of lifetime distribution which may be used. The simplest is termed single discrete and assumes that all consumption arises in a single year one lifetime later. In practice, scrap does not arise in a single year but over a period and this is termed single normally distributed (Figure 8.7) it is assumed that the scrap arisings are normally distributed about the average lifetime. In practice, actual distributions are probably not normally distributed but skewed to one side - termed single skewed distribution in Figure 8.7.

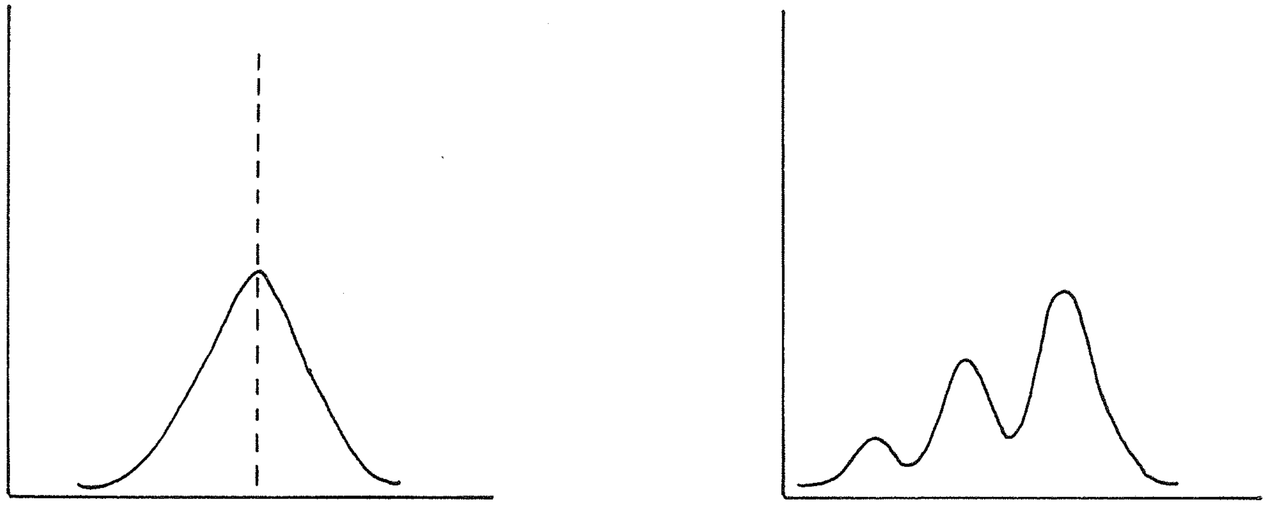
Examination of available statistics summarised in Table 8.3 shows that, in the case of copper, not all past consumption has a single average lifetime but that average lifetimes of ten, fifteen and thirty years occur. In this case one of the types of lifetime distribution termed multiple discrete, multiple normally distributed and multiple skewed distribution may reflect the real pattern of copper scrap arisings.

Figure 8.7 - Various Types of Life-Time Distributions



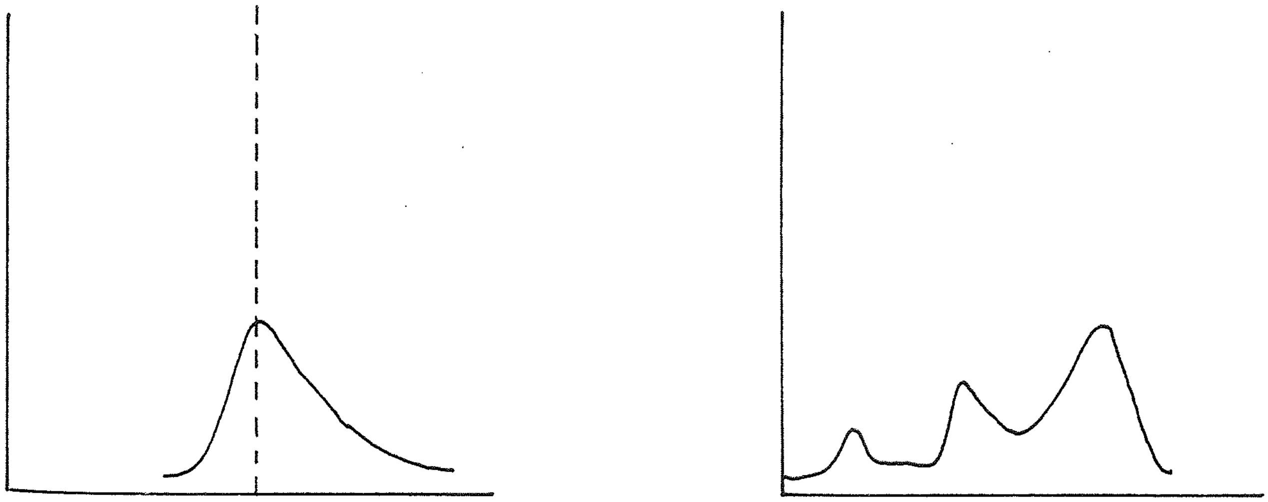
1. SINGLE DISCRETE

2. MULTIPLE DISCRETE



3. SINGLE NORMALLY DISTRIBUTED

4. MULTIPLE NORMALLY DISTRIBUTED



5. SINGLE SKEWED DISTRIBUTED

6. MULTIPLE SKEWED DISTRIBUTED

The determination of distributed lifetimes, whether normal or skewed, is possible only when a large volume of statistical work has been collected as obsolete goods may arise over a period of 5, 10 or 15 years for example. This is reflected by the fact that only the transport uses of copper in cars can be said to have a statistically proven lifetime distribution (150,151). Owing to this lack of statistical evidence and limits on the time available, one of the other simpler lifetime distributions in Figure 8.7 has had to be adopted. Chapman (152) and Alexander and Appoo (88) suggested that the use of a smoothed historical time series of consumption and a single discrete lifetime approximates to the true, distributed case by removing the peaks and troughs in historical consumption. The disadvantage of smoothing is that the method of smoothing can affect the results. For example, Chapman smooths the period 1943 to 1970 by fitting an exponential function, which is not an accurate fit for the relevant period for this work (1922-1976). By using the multiple discrete lifetime estimates given in Table 8.3 and an actual historical time series for consumption a more accurate assessment of scrap arisings can be made, with the multiple lifetime function smoothing out most of the sharp fluctuations in consumption. The sensitivity of the results obtained to changes in lifetime and end-use patterns will be investigated later in this chapter.

8.5.6 Estimates of the Recoverability Factor for Copper

Not all the copper consumed in any one year is actually recovered. Dissipative uses have already been described (section 8.5.3) but in addition some copper which is potentially recoverable is rarely actually recovered. A recoverability factor, expressing actual scrap recovery as a fraction of scrap arisings, takes these uses into account. Recoverability factors for copper vary between 75% (Merril (141)), 65% (U.N. (155)), 45% (Landberg (143)), 41% (Battelle (144)) and 31% (Carrillo (153)).

Care must be taken in using these figures on two points. Firstly, it is necessary to ensure that the figure used refers to the relationship between potential and actual old scrap supply. For example, a commonly quoted figure from the Battelle study (144) is a recoverability factor of 61%, but this relates potential and actual total (old and new) scrap supply. Another figure, quoted in the Battelle study and above, of 41% is applicable to potential and actual old scrap supply. Secondly, it is sometimes difficult to determine whether the recoverability factors quoted refer to the relationship between total potential old scrap arisings and actual old scrap withdrawals (i.e. actual recovery levels) or to total potential old scrap arisings and theoretically recoverable old scrap arisings (i.e. potential recovery levels). For example, Merril quotes two figures, firstly that 75% of copper consumption in fabricated goods is recoverable (i.e. 25% dissipative uses) and that 31% is actually recovered. The Landsberg figure of 45% relates to potential recovery levels and the U.N., Battelle and Carrillo figures to actual recovery levels.

The wide range of figures quoted for both potential and actual recoverability levels means that no single figure has been selected and instead, potentially recoverable scrap arisings will be compared to old scrap withdrawals to obtain figures for the U.K.

8.5.7 Model Results - Annual Potentially Recoverable Scrap Arisings

Using the data developed in Sections 8.5.2 to 8.5.6, annual potentially recoverable scrap arisings were calculated for the period 1952 to 1976. An allowance of 5% (Section 8.5.3) was made for dissipative uses, but no allowance was made for a recoverability factor, which will be developed in this section.

A decision whether to use smoothed or actual consumption data has to be made and the effects of abnormal copper consumption patterns during World War II investigated.

The pattern of potentially recoverable scrap arisings calculated using actual consumption data for the period 1952 to 1976 is shown in Figure 8.8. It can be seen that peaks in annual scrap arisings occured in 1957 and 1972 due to the abnormal final consumption patterns for copper over World War II. Table 8.4 shows those years for which scrap arisings are affected by World War II (1940-44) using lifetime estimates from Table 8.3. The only years which are not affected are 1960 to 1969 inclusive, indicating that the war years and their effect merit special attention.

Table 8.4 - Years for which annual scrap arisings are affected by World War II

Lifetime	Year Affected
10 years	1950-1954
15 years	1955-1959
30 years	1970-1974

During World War II, most copper consumption was by the war industries and a considerable proportion of consumption must have been in end-uses with untypical lifetime expectancy. Exactly what proportion of this unusual consumption pattern was returned to the U.K. either during or after the war in the form of spent shells, damaged ships or vehicles or other obsolete war materials is difficult to estimate; records for the war years are incomplete and in some cases are not available to the public. In view of this scarcity of data it has been assumed that the final consumption of copper goods between 1940 and 1945 inclusive is equal to the predicted values using exponential smoothing over the period 1946 to 1970. The effect upon annual scrap arisings (Figure 8.8, dotted line) is to remove the very large peak around 1972 and to reduce the 1957 peak. Also, a more gradual trend in annual scrap arisings becomes apparent, as would be expected in the real world. From Figure 8.8 it can be seen that 300,000 tonnes of potentially recoverable scrap became available in 1976.

Figure 8.8 also shows annual potentially recoverable scrap arisings calculated by using exponentially smoothed consumption data over the whole period considered and end-use and life-time estimates from Table 8.3. Annual scrap arisings are more stable than in the case of actual data with a readily observed trend but it was felt that scrap arisings estimated by using actual consumption data with the war years smoothed more satisfactorily described the real world. Nevertheless, the size of the pool of potentially recoverable scrap will be estimated in the next section using both methods to compare the quantities involved.

Finally, Figure 8.8 shows how much old scrap was used by scrap consumers over the same period, as calculated in section 5.3.5. By comparing scrap arisings with old scrap used it is possible to estimate typical actual recoverability factors for copper scrap as described in section 8.5.6.

This figure varies from 66% in 1975 to 14% in 1952 with an average of 52%. This compares well with published estimates (section 8.5.6) of 31% (141), 65% (155), 41% (144) and 31% (153), and indicates that the UK is relatively efficient in its copper scrap recovery activities.

Using the data in Figure 8.8, which assumes 5% dissipative uses, it is estimated that approximately 180,000 tonnes of potentially recoverable old scrap was not collected in 1976. This compares well with another estimate of 147,000 tonnes by Bridgwater (156), using a simpler method based on the Battelle methodology (144). The location of this unrecovered scrap will be discussed in Section 8.7.

Having developed a model of scrap arisings, the results obtained will be used in Chapter 9 as a possible component in models of copper scrap demand. As the above estimates of dissipative uses and a recoverability factor are uncertain, the time-series used will be gross annual potentially recoverable scrap arisings i.e. before allowances for dissipative uses and application of a recoverability factor.

Having calculated annual scrap arisings, the next section estimates the size of the pool of potentially recoverable scrap.

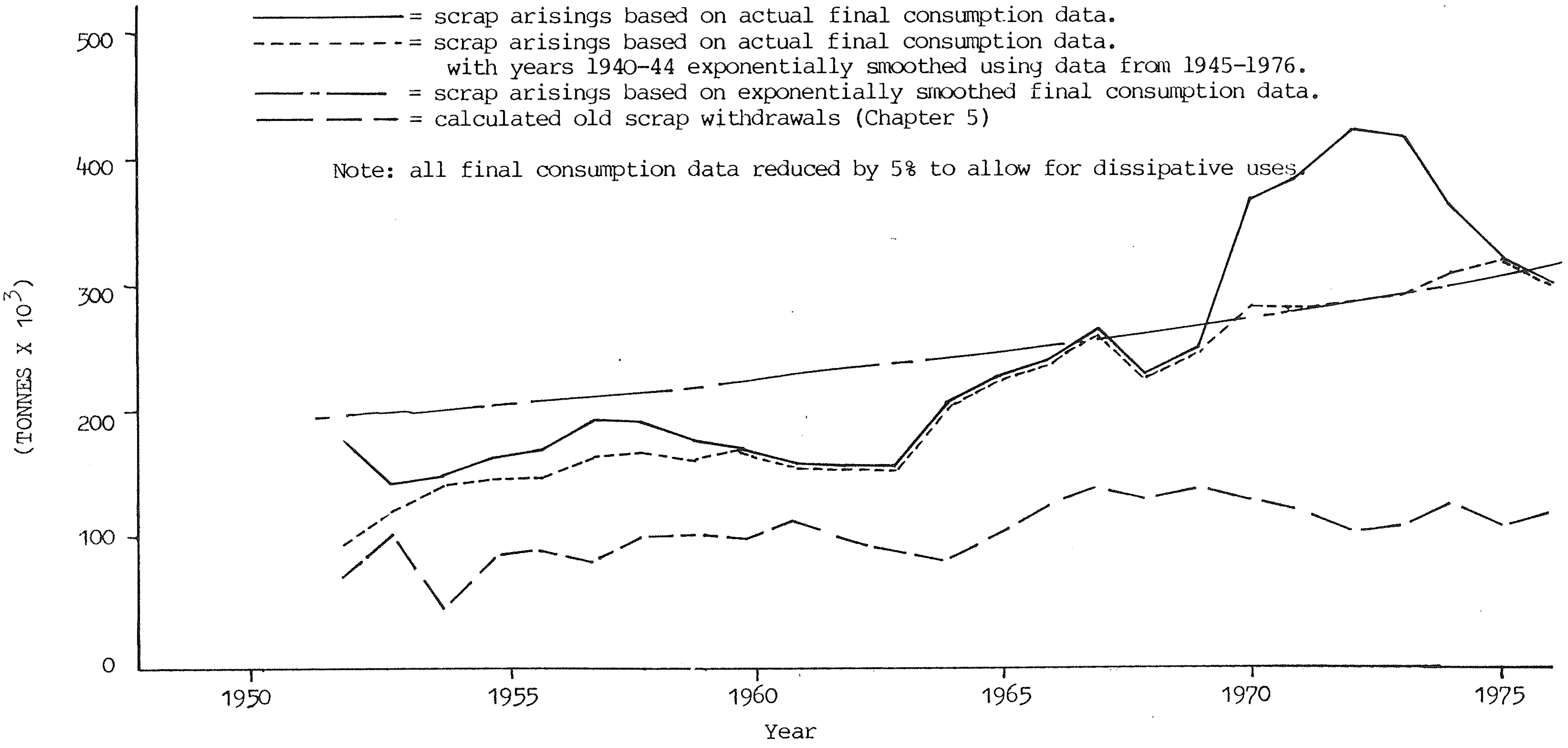


Figure 8.8 - Calculated Annual Potentially Recoverable Scrap Arisings and Calculated Old Scrap Withdrawals

8.6 Estimating the Size of the Pool of Potentially Recoverable Scrap

The size of the pool of potentially recoverable scrap may now be calculated by summating annual potentially recoverable scrap arisings. After making allowances for old scrap withdrawals (totalling 2757 x 10^3) tonnes over the period 1952 to 1976) the size of the semi-permanent pool of potentially recoverable scrap described in section 8.4.2 may be calculated. The size of this pool indicates the potential for increased copper recycling effort. After calculating the semi-permanent pool size the likely location of the 180,000 tonnes of unrecovered potentially recoverable scrap arisings in 1976 will be described.

8.6.1 Base Case Estimation of the 1976 Potentially Recoverable Scrap Pool Size

Table 8.5 shows base case estimates of the potentially recoverable scrap pool size calculated by summating the estimates of annual potentially recoverable scrap arisings developed in Section 8.5. The base case assumes that the pool size in 1951 was zero as final consumption data is only available from 1922 and the maximum lifetime assumed is 30 years. In addition to the base case, Table 8.5 also shows the effect of using single (24 years average assumed) and multiple discrete lifetime functions with actual and exponentially smoothed consumption time-series (see Section 8.5.5).

Table 8.5 - Pool Sizes 1976 ; Base Case (tonnes x 10^3)

Lifetime function / Time series	Multiple discrete	Single discrete (24 years)
Actual	5346	5572
Smoothed	6261	6276

Table 8.5 shows that the type of lifetime function and time series assumed has little effect on the pool size in 1976 with the base case being 5.3 million tonnes.

8.6.2 The Effect of End-Use Estimates on Pool Size

The scrap pool size for various end-use estimates using actual time series for copper consumption are given in Table 8.6, together with the percentage change from the base case. Not surprisingly, it may be concluded that the pool size is controlled by the large proportion of annual consumption with a lifetime of 30 years. Variation in the proportion of consumption attributable to the other two lifetime values show only small variations from the base case.

Table 8.6 - Sensitivity of End-use Estimates on 1976 Pool Size

% of consumption at each lifetime value			1976 Pool size (tonnes x 10^3)	% variation from base case
10 years	15 years	30 years		
15	15	70	5346	base case
0	15	85	4753	-11
0	30	70	5210	-3
30	0	70	5483	+3
15	0	85	4889	-9
50	50	0	7797	+46

8.6.3 The Effect of Lifetime Estimates on Pool Size

The pool size for various lifetimes of copper goods are shown in Table 8.7. Again, only variations in the lifetime of the largest end-use produces any significant change in the pool size compared to the base case. Generally, the variations are smaller than when the end-uses were varied (Table 8.6).

Table 8.7 - Sensitivity of Lifetime Estimates on 1976 Pool Size

Lifetime estimates for the end-use percentages shown			1976 Pool size (tonnesx10^3)	% variation from base case
15%	15%	70%		
10	15	30	5346	base case
5	15	30	5418	+1
15	15	30	5210	-3
10	10	30	5483	+3
10	20	30	5195	-3
10	15	25	6092	+14

8.6.4 Estimating the 1946 Scrap Pool Size

In the previous sections it has been assumed that the pool size was negligible at the end of World War II. This assumption is important if the size of the scrap pool in any year can influence the supply of old scrap. The assessment of pool size in 1945 is complicated by lack of data for the early part of the 20th century on the historical consumption of fabricated copper goods and old scrap withdrawals.

Two methods were employed to estimate the 1945 pool size. The first method used is given below:-

1. Linear growth in the consumption of fabricated copper goods was assumed. Pre-1939 data was backcasted from the trend in consumption between 1945 and 1967.
2. A single discrete lifetime of 15 years was assumed. While lower than the 24 years used earlier in section 8.6.1, this assumption will produce a larger 1945 pool size. This shorter single discrete lifetime also enables more years final consumption to contribute to the pool size than would be the case if multiple discrete lifetimes were used.

3. Although step 1 above results in zero consumption of fabricated goods in 1912, so implying that old scrap did not arise until 1927, this has been balanced by assuming that no old scrap was consumed until 1939.
4. The 1945 to 1976 average of 25% old scrap contribution to scrap supplies (section 5.4) has been assumed to apply to the pre-1945 period and no extra recovery effort was introduced during World War II.
5. A potential recoverability factor of 60% of copper consumption (average of estimates given in Section 8.5.6) has been assumed.

Using the above method, it was calculated that in 1945 a scrap pool of 390,000 tonnes existed. This may be explained by the assumption that no old scrap recycling occurred prior to 1939. If linear growth, similar to that for final consumption of copper goods, is assumed for old scrap recovery from zero in 1927 to the 1939 level, than a surplus of scrap consumption over scrap arisings occurs in 1945.

For the second method, the following method was adopted:

1. Exponential growth in the consumption of faricated copper goods was assumed. Pre 1939 data was back casted from 1945-1967 data.
2. A single discrete lifetime of 24 years was assumed.
3. Exponential growth in scrap consumption from 10,000 tonnes in 1914 to the 1939 value was assumed.
4. 25% old scrap consumed assumed (see first method).
5. 60% recoverability factor assumed (see first method).

Using the above method, the 1946 scrap pool size is calculated to be 721,000 tonnes. This may be attributed to the assumption that no recycling took place prior to 1914 and that a higher recovery rate for copper scrap was experienced during World War II. A recovery rate of about 70% for old scrap would account for the surplus of 721,000 tonnes which although high, is possible.

It must be concluded that the pool sizes calculated in sections 8.6.1 to 8.6.3 may be subject to an error of up to a maximum of 721,000 tonnes (or ±13%).

8.6.5 Estimating the Size of the 1976 Semi-Permanent Pool of Potentially Recoverable Scrap

In Sections 8.6.1 to 8.6.4 it was established that the pool of potentially recoverable scrap before allowing for old scrap withdrawals was 5,346 x 10^3 tonnes in 1976. The size of the semi-permanent pool of potentially recoverable scrap may be calculated as follows:-

$$\begin{array}{lcl}\text{Semi-permanent pool} & & \text{Size of potentially} & & \text{Old scrap} \\ \text{of potentially recoverable} & = & \text{recoverable scrap} & - & \text{withdrawals} \\ \text{scrap} & & \text{pool} & & \text{1952 - 1976}\end{array}$$

$$= (5346 \times 10^3) - (2757 \times 10^3) \text{ tonnes}$$

$$= 2589 \times 10^3 \text{ tonnes } (\pm 13\% \text{ - Section 8.6.4})$$

This means that by 1976, 2.6 million tonnes of potentially recoverable copper scrap had not been recovered over the period 1952 to 1976. This is equal to about 21 years supply of old scrap at the 1976 level of consumption.

While not as detailed as the analysis in this work, Alexander and Appoo (88) constructed a balance sheet for U.K. copper consumption for the years 1920 - 1970. After allowing for 3% dissipative uses and 8% net capital goods exports, net copper consumption over the period was estimated to be 14.8 million tonnes. Analysing Alexanders figures further and assuming a rounded single discrete lifetime of 20 years, then 5.9 million tonnes of copper scrap would become potentially available over the period 1940 to 1970, of which 3.6 million tonnes was assumed by Alexander to arise as old scrap. In this case a semi-permanent pool of 2.3 million tonnes would exist in 1970.

Tron (157) estimated that 2.5 million tonnes of copper were in stock awaiting possible recovery. While cruder than the methodology used in this work to model scrap supply, Alexanders figures do support the results obtained above and by Tron, i.e. that a semi-permanent pool of 2.6 million tonnes of potentially recovered scrap exists in the U.K.

8.7 Examination of the Location of Unexploited Potentially Recoverable Copper Scrap

In section 8.5.7 it was calculated that about 180,000 tonnes of potentially recoverable copper scrap was not recovered in 1976. In section 8.6.1 similar unexploited scrap arisings for the period 1951 to 1976 were estimated to total 2.6 million tonnes. In this section it is intended to provide realistic estimates of the fate of this unrecovered copper. While not vital to the overall project aims, such an analysis provides an insight into the potential for increased copper scrap recovery.

The only detailed breakdown of the sources of UK old copper scrap found was by Whalley and Broadie (42) whose results are presented in Table 8.8.

Table 8.8 - Estimated Copper Content of Uncollected Potentially Recoverable Copper Scrap (42)

Source	tonnes x 10^3
Domestic refuse	24
Cars	2
Commercial vehicles and tractors	2
Demolition	1.2
General industrial waste	10
Ships exported for breaking	2.3
Long term preservation	6
Defence and munitions	No data
Explosives, detonators etc.	1
Shipwrecks	0.5
Redundant power and submarine commun. equipment.	7
Inland telecommunication cable	No data
TOTAL	56

Table 8.8 shows that the largest uncollected copper flows are domestic refuse and general industrial waste. Whether this is due to the availability of statistics on the metal content of these flows is largely irrelevant, as only 56,000 tonnes of copper scrap are accounted for in Table 8.8. In particular, the lack of data on defence and munitions scrap and inland telecommunication cable may account for significant quantities of copper scrap.

The eventual fate of defence and munitions scrap is difficult to determine. If small arms and artillery shells are fired at domestic or foreign military bases then copper scrap, in the form of shell casings, becomes available. In the case of small arms these shells will be scattered in small quantities over large areas and are unlikely to be recovered. Artillery shells will be scattered in a similar way, but being of higher individual value and easily recognised and recovered, are much more likely to be collected. It is difficult, if not impossible, to estimate the quantities involved and no attempt has been made here other than an educated guess that these losses would be large.

The quantity of redundant telecommunication cable unexploited each year is also difficult to determine. If a fault develops on a telecommunication line, a new cable would be installed. The decision to recover the old cable depends upon the cost of recovery, which would be high if underground cables were involved. Although Whalley and Broadie estimated that 7000 tonnes of redundant power and submarine communication equipment scrap is unexploited annually, a similar argument to that for inland telecommunication cable may apply, that is, difficult to recover cable (for example cable in empty tenement blocks or underground on recently demolished inner city sites) may not necessarily be recovered. Once the site has been redeveloped the cable is lost to potential recovery until the site is barren again. The extent to which Electricity Boards recover copper scrap is unknown, but it is suggested that large volumes of copper scrap are lost in this way.

Whether the 120,000 tonnes of unexploited copper scrap unaccounted for in Table 8.8 can be allocated to the uses described above is unclear. Even with high dissipative uses of 25% as suggested by Merrill, 1976 annual potential scrap arisings would be 237,000 tonnes, of which 123,000 tonnes was recovered (at an actual recoverability of 52%) leaving 104,000 tonnes unaccounted for.

Detailed data on the location of unrecovered copper scrap is needed, but is beyond the scope of this project and it must be concluded that significant sources of copper scrap cannot be identified at present.

8.8 Summary to Chapter 8

After defining copper scrap supply and demand, a qualitative assessment of the factors affecting new and old copper scrap supply was made. It was concluded that new scrap is generally price inelastic and moves quickly from the fabricators back to the semi-manufacturers. Old scrap generation was considered to be a largely automatic process although periods of high scrap prices would result in more old scrap being recovered.

After reviewing methods of describing potential and actual scrap arisings, models were constructed of potential scrap supply and compared with actual scrap supply. The UK was found to be generally more efficient at copper scrap recovery compared to other, mostly U.S. reported figures. The size of the 1976 semi-permanent pool of potentially recoverable scrap was estimated to be 2.6 million tonnes ±13% and 1976 unrecovered copper scrap arisings to be 180,000 tonnes.

The location of unrecovered copper scrap was examined. It was concluded that domestic and industrial wastes, together with unrecovered underground power and telecommunications equipment and military uses, were the major locations.

CHAPTER 9 - MODELLING U.K. DEMAND FOR COPPER SCRAP

9.1 Introduction

In Chapter 8 the factors affecting the supply of copper scrap were examined and a model of annual potentially recoverable scrap arisings constructed. In order to determine the effects of future trends in scrap supply it is necessary to develop a model of scrap demand. By comparing scrap supply and demand using the models developed here and in Chapter 8, future imbalances and opportunities for increased recycling activity identified. By constructing a causal model of scrap demand, the factors affecting demand can be isolated and possibly used in later chapters to evaluate the effects of various policy decisions.

9.2 Measures of U.K. Demand for Copper Scrap

Figure 9.1 shows the copper flows involved in the supply and demand for copper scrap (see Figure 8.1). As discussed in Section 8.2 copper scrap demand is defined as the flow of copper scrap from the scrap merchants (and possibly directly from the fabricators) to the scrap users.

Copper scrap demand may be classified in several ways, the more common being listed in Table 9.1.

Table 9.1 - Various Classifications of Copper Scrap Demand

Classification	Description	X-ref	Comments
1. Total demand	Total scrap consumed by user industries	Section 5.3.5	Calculated in Section 5.3.5 by summing demand by grade.
2. Demand by grade	Demand broken down by scrap grade.	Section 5.3.5	Normally simplified into 2(a) and 2(b).
(a) High grade	Demand for high grade scrap - measured by direct use of scrap.	Section 5.3.5	Direct use of scrap - a calculated not measured value (section 5.3.5).
(b) Low grade	Demand for low grade scrap - measured by the production of secondary refined copper	Section 5.3.2 and 5.3.5	Consumption of scrap assumed to equal production of refined copper i.e. 100% efficiency.
3. Demand by source	Demand broken down into new and old scrap.	Section 5.3.3	No measured U.K. data - assumptions used in calculating new and old scrap demand open to doubt.
4. Demand by destination	Demand broken down by end-use.	Section 4.3	No time series available on end-uses. Demand by shape group (section 5.3.3) too complex to model here.

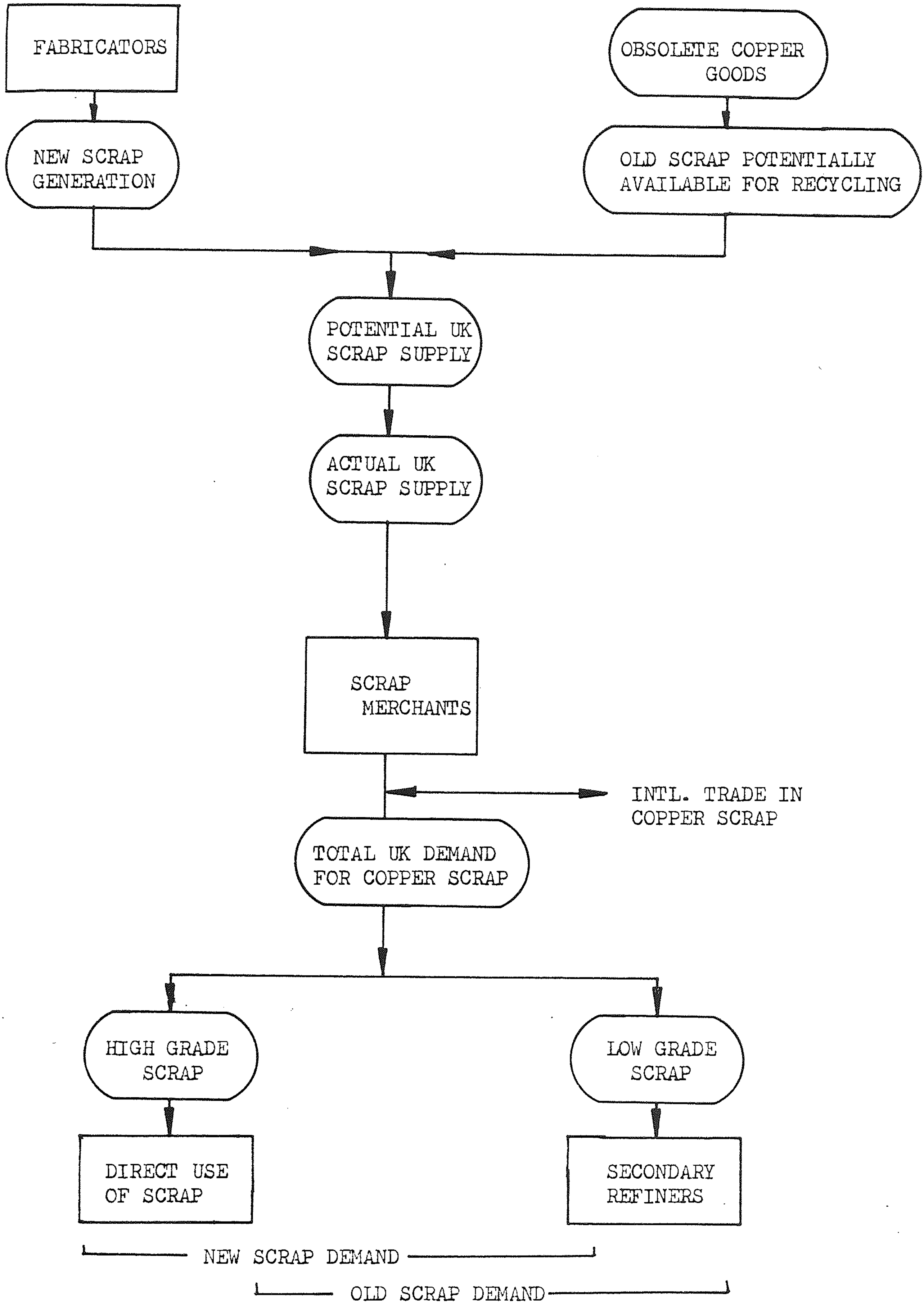


Figure 9.1 - Flows Involved in the Supply and Demand for Copper Scrap

Lack of statistical data, as noted in Table 9.1, limits the initial modelling effort to the total demand for copper scrap and demand by grade, broken down into the production of secondary refined copper and the direct use of scrap.

9.3 Literature Review of Copper Scrap Demand Models

No quantitative work on modelling U.K. copper scrap demand was found and only three readily available studies for the U.S. were found. This lack of published U.K. information is probably due to the complex econometric modelling identified in Section 6.2.4 as being necessary to comprehensively model copper scrap demand.

Lack of available U.K. statistics also hinders U.K. model development. In particular, U.S. copper statistics, unlike U.K. statistics (section 5.3.5), provide information on the breakdown between old and new scrap consumption.

Two of the U.S. studies were compiled by Charles River Associates (CRA) for the General Services Administration of the U.S. Government in 1970 (130,131). The first report (130) details a qualitative analysis of the U.S. copper industry and the development of a series of econometric equations. The second report (131) summarises the model itself and other alternative models. While of considerable interest to this project, the models developed are of limited application to the U.K. copper industry as a large proportion of US refined copper arises from indigenous primary sources and so are, therefore, subject to similar economic pressures to the US secondary copper industry. This tends to stabilise the balance between primary and secondary supplies in the U.S. In the U.K., no significant economic domestic sources of copper ore are available (section 4.2.2) and the U.K. secondary copper industry, influenced by U.K. economic factors, has to compete with imported refined copper supplies which are subject to a different set of economic factors.

The CRA models were generally successful for the demand of new scrap but less successful for old scrap demand.

The third study available was by Fisher, Cootner and Bailey (129) who also developed econometric models of the U.S. copper industry. Additionally, non-U.S. copper industries (grouped under a Rest-of-the-World heading) were modelled with less success than the U.S. models. No multiple correlation coefficients are given, but low t-statistics imply inaccurate models. Moreover, the Rest-of-the-World system only considers total scrap demand while the U.S. system is broken down into scrap source (see section 9.2) because of readily available U.S. statistics on new and old scrap collection.

9.4 Model Development

9.4.1 Introduction

A whole range of complex factors affect scrap demand, as measured by the three flows from the scrap merchants identified in Section 9.2

As many individual factors as possible will be identified in the following sections and incorporated into a final list of variables to be used in modelling scrap demand. This list is given in Table 9.2 in Section 9.5.

9.4.2 The Dependent Variables - Scrap Demand

Three models of scrap demand will be constructed (section 9.2) requiring the selection of a dependent variable for each model.

a) Total copper scrap demand model - Total scrap demand may be measured at two points after the scrap merchants in Figure 9.1. Firstly, by the quantity of copper scrap consumed by U.K. scrap consumers or secondly, by the total quantity of copper scrap supplied by the scrap merchants, which includes international trade in copper and copper alloy scrap.

Arguments may be presented for both measures, but international trade in copper and alloy scrap is overall a small, but sometimes significant aspect of copper demand (see Table 5.8). As exports of scrap are normally much larger than imports and is the relationship between scrap supply and demand is of particular interest, it was decided to use the total scrap collected in the U.K. as the dependent variable in the model of total scrap demand.

b) Consumption of scrap by the secondary refiners model - Lack of empirical data on scrap consumption by the secondary refiners (Section 5.3.5) means that the dependent variable in this model will be the production of secondary refined copper.

c) Direct use of scrap model - calculated data on the direct use of scrasp was compiled in section 5.3.5 and will be used in this model.

9.4.3 Activity Level of the Copper Industry and New Scrap Generation

Demand for copper scrap basically reflects demand for copper goods produced by the manufacturers which takes into account for example, substitution by competitive materials.

If semis consumption rather than production is used an interesting paradox arises. New scrap is generally a high value scrap moving quickly between the points of generation and consumption (section 8.3) and is principally a function of semis consumption, which therefore needs to be included in any model of scrap demand. International trade in semis is small, with the exception of unalloyed wire, and models including both semis production (reflecting activity level) and semis consumption (reflecting new scrap generation) would produce models that exhibit multicollinearity (Appendix 1) resulting in low t-statistics for the two variables.

While other, more general, measures of activity level are available, such as the Index of Industrial Production used in Chapter 7 to model semis production, these measures are not considered as pertinent to the models involved as either semis consumption or semis production. In view of the close relationshilp between semis production and scrap demand it was decided to use total semis production as an independent variable in the models of scrap demand.

Copper scrap is used by the semi-manufacturers to different, but unknown, extents depending upon the shape-group being produced and it was decided to include unalloyed and alloyed semis production as additional independent variables to total semis production. Ideally, independent variables should be included to reflect each shape group, but the practicalities of modelling large numbers of variables in the time available prohibits their inclusion.

9.4.4 The Price of Copper Scrap

Copper scrap is generated, collected, processed and consumed by a large number and variety of concerns each with varying needs and different market orientation. For these reasons, the effect of copper scrap price is a complex problem and only the broad principles will be discussed here. Other independent variables would also appear to depend upon the price of copper and copper scrap (for example, the level of refined copper imports) and these will be discussed separately in later sections.

The effect of copper price upon both copper scrap supply, as well as demand, will be discussed in this section. No actual measure of U.K. copper scrap supply was available (see section 8.2), for modelling in Chapter 8 and so will be incorporated in the development of the model of copper scrap demand.

The general effect of copper price (which, in section 6.3.5 was shown to be directly linked to LME refined copper price) upon the supply/demand of copper scrap is shown in Figure 9.2.

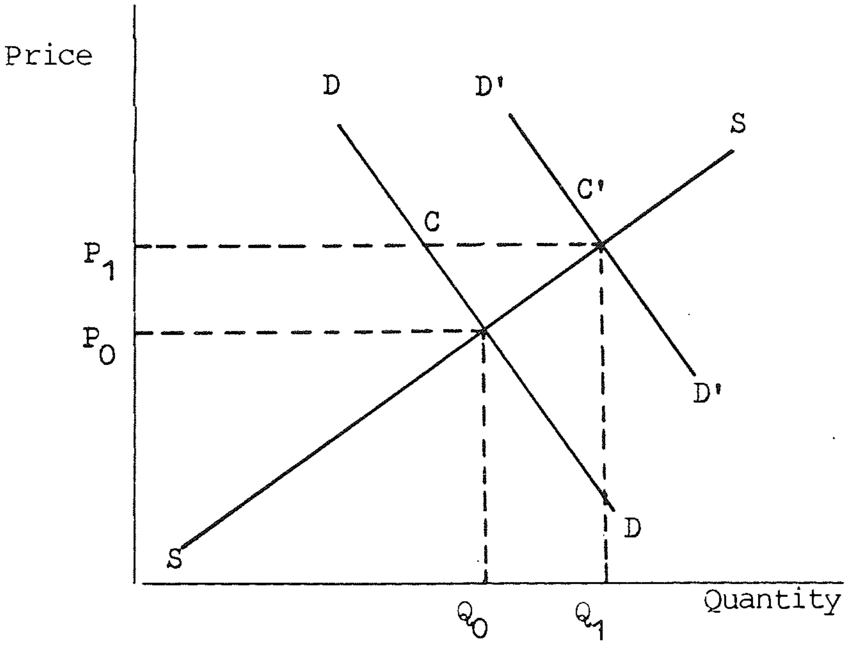


Figure 9.2 - Supply, Demand and Price Relationships for for Copper Scrap

Curve D-D represents the quantity of scrap that will be demanded by the consumers (at a given level of production), dependent upon price. The curve S-S indicates the supply of scrap at various prices and depends upon scrap generation rates and the costs involved in their collection and sorting i.e. scrap merchant costs. The market will clear at point C with the quantity Q_o supplied and demanded at price P_o. If demand increases and moves the demand curve to D'-D' then a new price P_1 will be established and a new quantity Q_1 demanded.

Demand for copper scrap basically reflects the competition between virgin and secondary copper to satisfy the needs of the scrap consumers, in a similar way to which copper and its principal substitute, aluminium, compete to supply consuming industries. Because of this similarity many of the factors discussed in Chapter 7 as affecting demand for copper goods may be relevant here.

In the main, virgin and secondary copper are interchangeable and from the copper users point of view there are no distinct demands for primary and secondary copper although, for example, refined copper for technical reasons is almost exclusively used in electrical cable industries. Instead, a total market demand for copper interacts with a primary and a secondary supply sector. The proportion of total demand satisfied by the secondary sector depends mainly upon the cost of using metal from this sector relative to the primary sector.

In the U.K., a small proportion of virgin demand is met from U.K. refined production, mainly associated with vertically integrated plant (see sections 4.4.2, 4.4.3 and 5.3.2). The balance of U.K. primary demand is met from refined imports, while the balance of total copper demand is met by secondary refined copper and directly used copper scrap. Demand for secondary refined copper is, therefore, likely to be affected by world supply and demand for refined copper and this will be discussed in more detail in section 9.4.5. Demand for directly used scrap will be influenced by the semi-manufacturers costs of using scrap compared to refined copper. The principal cost difference affecting the semi-manufacturer is the price of raw materials i.e. scrap and refined copper, but it has already been decided (section 6.3.5) to use a single price measure to cover both materials. This would indicate that future clarifying work is necessary in this area.

Copper prices, however, do affect the quantity of directly used scrap by encouraging greater old scrap recovery effort. If world demand for refined copper exceeds the short-term fixed primary supply then LME copper prices rise. The flexibility of the scrap merchants compared to the copper refiners, combined with the shortage of refined copper and high prices, encourages greater recovery of old scrap, either by upgrading low grade scrap or by recovery from more remote areas. As world supply and demand stabilise over a longer period, more refined copper becomes available, LME prices drop and less scrap is used directly by the semi-manufacturers.

The ability of the scrap market to satisfy the fluctuating demand identified above centres upon the role of the scrap merchants (see sections 4.2.8 and 8.4) with an upper limit to scrap supply being the size of the annual potentially recoverable scrap arisings (see section 9.4.8). At times of high scrap prices, scrap merchants not normally involved in copper scrap are prompted by potential high profits to enter the market, compete for supplies and force scrap prices up. Scrap prices are also forced up by the higher collection costs of upgrading low grade scrap or collecting from remote areas. As primary supplies become available, the speculative merchants drop out of the market and the higher cost processes are discarded until equilibrium is reached.

A separate independent variable to allow for these collection costs has been included in the model specification (see section 9.4.6).

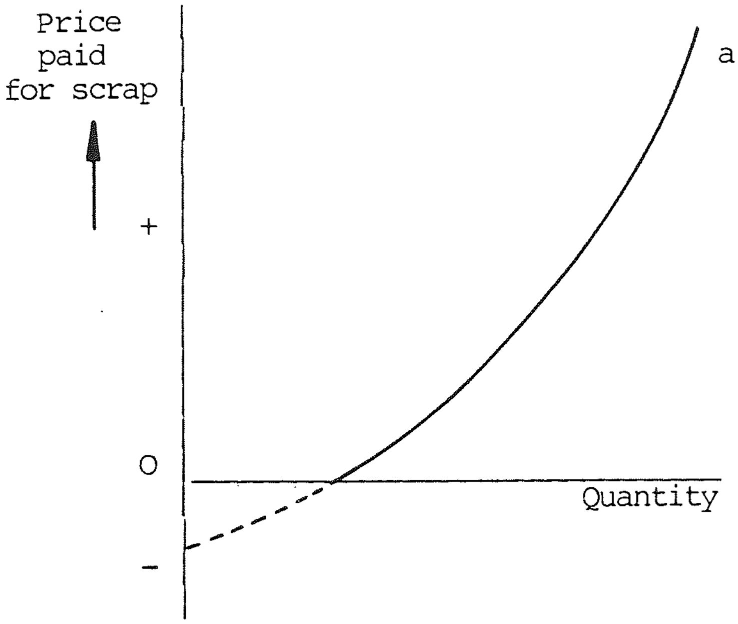
The overall effect of copper prices as described above upon scrap supply is shown in Figure 9.3 (130, 135, 140).

Figure 9.3(a) shows the effect of price paid by the scrap merchants upon the amount of scrap supplied from the point of generation. At high prices large volumes of waste become available to the merchants, while at the other end of the price range some people will pay to have scrap removed. Figure 9.3(b) depicts the average costs, including return on capital invested, of collecting and processing the scrap generated in Figure 9.3(a) and it has been assumed that the recovery of larger volumes of scrap will result in increased costs due to the recovery of progressively lower grades of scrap and recovery from more remote areas. Finally, Figure 9.3(c) represents the supply curve for scrap from the scrap merchants and processors. The supply curve is shown to have a certain degree of price elasticity in accordance with the arguments presented earlier. If home scrap were included in Figure 9.3(c) then the horizontal section would be extended and the entire curve would be less price elastic.

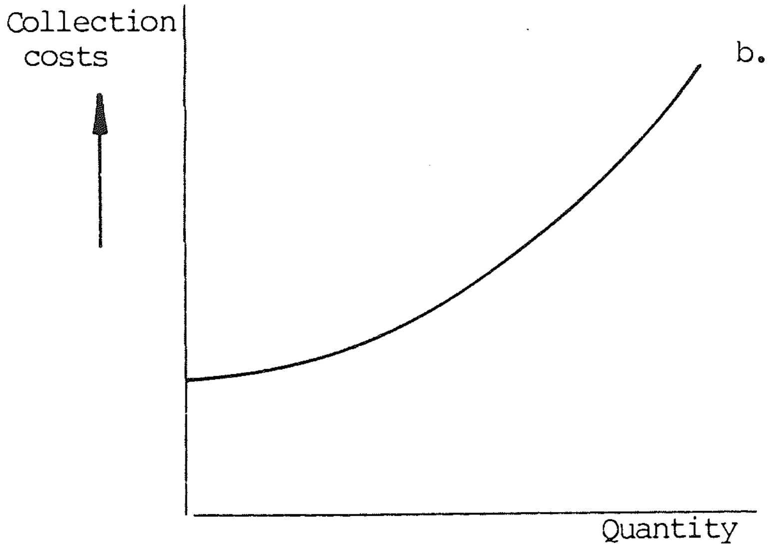
The analysis presented in this section has shown that the price of copper is an important factor affecting both the supply and demand for copper scrap. Other independent variables (see Sections 9.4.5 and 9.4.6) have been included to allow for the effects of copper price which cannot be directly modelled by copper price alone.

The LME price of copper, deflated by the index of raw material costs (Section 6.3.4), has been included in the model specification in Table 9.2. Both current prices and prices lagged by one year have been included.

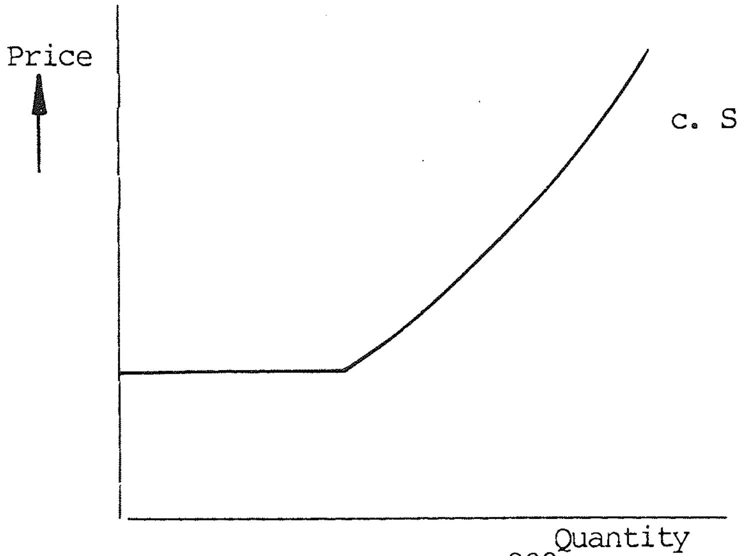
Figure 9.3 - Response of Scrap Supply to Price Changes (130, 135, 140)



a. Scrap and waste supply from point of generation.



b. Collection costs incurred by the scrap merchant.



c. Supply curve for collected and processed scrap.

9.4.5 Restrictions on Refined Supplies

In Section 9.4.4, limitations on primary refined copper supplies were identified as being a possible major influence on scrap demand. Gordon (135) suggested that if primary sources were a fixed source of supply (known as the Marshallian market supply case), the market sysltem would be one of arbitrary allocation of limited supplies amongst customers. Grey markets would develop where more profitable customers could buy metal away from less profitable customers. Under ideal conditions all the supply would be demanded and reallocated to its most valuable users at a price which equated the quantity demanded to output. If the price drops, demand increases but supply is fixed and grey markets would develop where those users with the increased demand would resell to those users willing to pay the higher equilibrium price.

Reality is complicated by the existence of a vertically integrated copper industry and the existence of alternative sources of supply, primarily imported refined copper, scrap, stocks and substitute materials. The allocative process for virgin refined copper described above limits refined copper supplies to the U.K. and may be described in one of several ways including: world supply/demand relationships; the percentage of U.K. refined supplies from net imports of copper and by dummy variables for strikes, political disturbances and other factors limiting virgin refined supplies.

Dummy variables are commonly used in U.S. scrap demand models (129,130) where accurate statistics, combined with a large indigenous primary copper industry makes their application successful. Similar dummy variables relevant to U.K. imports of copper are impractical to construct requiring accurate statistics from the eight or so major supplying countries.

A world supply/demand relationship may be evaluated but its effect upon the U.K., now a minor copper consumer in comparison to the U.S. and U.S.S.R., is limited. In comparison, the percentage of U.K. refined supplies from net imports of refined copper reflects world supply/demand relationships while being a direct measure specific to the U.K. For this reason, the percentage of U.K., refined supplies from net imports of refined copper has been included in the model specification in Table 9.2 with both current and lagged values included.

9.4.6 Collection Costs

The amount of copper scrap supplied by the scrap merchants depends upon the profit to be made from collecting, sorting and possibly processing the metal into scrap. The firms involved attempt to maximise profits by comparing the market price of copper and the marginal costs at various levels of output. In the very short term, a firms capacity is fixed and its profitability can be increased or decreased only by decreasing or increasing the price paid for scrap.

Generally, scrap merchants buy scrap, possibly do some sorting and then resell at the price dictated by the market. If a scrap merchants costs are lower than the premium he can earn from partially upgrading the scrap, then he will upgrade. Tron (157) identifies this as a reason for the decline in secondary refining in the early 1970's as it became economical to sort scrap, previously destined for secondary refining, for direct use. This is partially due to secondary refiners needing an average of 15-16% copper in scrap to cover marginal costs. As a result, low grade copper scrap became less attractive and more sorting to direct use grades occurred.

Peck (158) and Gordon (135) identified a complaint by scrap merchants that in times of high demand and limited primary supplies (as described in the previous section), large copper consumers purchased (for a short time) large parcels of scrap at good discounts from the LME refined price. This forces down average scrap prices, reduces scrap merchant profitability and limits their ability to supply scrap copper. In the scrap merchants eyes, the integrated firms should have enough primary capacity to meet these demand peaks, even though this would lower scrap prices and reduce overall demand for copper scrap.

It has already been identified (Section 4.2.8) that scrap sorting is a labour intensive process and so an index of wage levels would be the simplest measure of collection costs. A more accurate measure would be to relate copper prices to wage levels to allow for situations where high copper prices relative to wage levels prompt increased scrap recovery. Table 9.1 includes a collection cost index measured by the ratio of the LME cash price for refined copper to the average weekly index of wage rates for manual workers (122). The collection cost index would be expected to be positively correlated to scrap demand.

9.4.7 Stock Changes

In Chapter 4 it was noted that scrap merchants act as the buffer between scrap supply and demand and, in particular, that stocks held by the merchant (and to a lesser extent, the user) act as the balancing figure between supply and demand.

As it takes approximately three months (83) for refined copper to be transported from its country of origin to the U.K., in the short term refined copper supply is fixed, apart from stocks held by the LME. In this case, scrap copper stocks have an important role to play and need to be included in any model of copper scrap demand.

As in the chapter on copper goods demand, no stock or stock change data are available for scrap copper and instead the methodology successfully adopted in chapter 7 has been used i.e. an index of general industrial stock changes (122) is included for both the current and previous years. The coefficient of current stock changes should be positive and the coefficient of the lagged stock changes negative.

9.4.8 Scrap Arisings

In chapter 8 it was noted that U.K. scrap demand could be limited by the amount of copper scrap becoming available each year for recycling. In Section 8.5.7 a model of the annual potentially recoverable scrap arisings was developed and will be included in the proposed model.

9.4.9 The Lagged Dependent Variable

In Chapter 7, copper goods demand was successfully modelled by use of the adaptive expectations theory. Reference to section 7.3.2 should be made for a complete description of the development of the model which may be summarised as:-

$$D_t = (1 - \lambda)\ D_{t-1} + \lambda a_1\ P_t + \lambda a_2\ X_t + \lambda a_o$$

where D_t = demand in current year

D_{t-1} = demand in previous year

P_t = price in current year

X_t = other factors affecting demand

λ = fraction of the gap between desired and actual demand made up during a single year.

a_1, a_2 = coefficients

It is proposed that the models of scrap demand will be of the adaptive expectations type and lagged demand will be included in Table 9.2. Interestingly, Fisher (129) used lagged demand as a measure of difficulty of collection by assuming that the amount of scrap available for recycling this year is governed by the intensity of recovery (or demand) in the previous year.

9.4.10 The Relationship Between Copper Prices and Prices of Other Metals

The recovery of copper scrap was identified in Chapter 4 as being only a part of most scrap merchants activities and the prices of other, possibly associated, metals will have an effect on copper scrap recovery. Tron (157) considered that low copper prices resulted in less separation of copper from other materials e.g. aluminium, nickel and lead. The model specification in Table 9.2 therefore includes the relationship used in Chapter 7 to model demands for copper goods i.e. the ratio of the price of copper to the price of aluminium. It is appreciated that other metals, and possibly non-metals, may be involved but Chapter 7 showed that the price of other principal metals relative to copper move similarly to aluminium and need not be considered separately. A possible exception to this rule is the price of steel scrap which, it has been suggested (159), may have a more direct effect upon copper recovery efforts.

9.5 Model Specification

Table 9.2 lists those variables identified in Section 9.4 as affecting scrap demand.

Unlike modelling copper goods demand in Chapter 7, it was not possible to put forward a basic model and investigate the effect of different variables. Instead models had to be constructed from basics for each measure of scrap demand as described in Section 9.6, 9.7 and 9.8.

Table 9.2 - Initial List of Variables Considered to Affect Scrap Demand

Variable number and shortened name	Description (all copper flows in terms of copper content)
1. Scrap	Either 1) Total scrap collected 2) Production of secondary refined copper 3) The direct use of scrap.
2. Sempro	Total semis production
3. Allsempro	Alloyed semis production
4. Unallsempro	Unalloyed semis production
5. Price	LME price of copper deflated by index of raw material costs.
6. % imports	% UK refined supplies from net imports of refined copper
7. Collcost	Index of collection costs LME cash price refined copper/Index of weekly wage rates (manual))
8. Stocks	General industrial stock changes
9. Arise	Annual scrap arisings - actual data
10. Scrap -1	Lagged values of variables 1-9 signified by -1 suffix.
11. Sempro -1	
12. Allsempro -1	
13. Unallsempro -1	
14. Price -1	
15. % imports -1	
16. Collcost -1	
17. Stocks -1	
18. Arise -1	
19. Pratio	Current and lagged values of the ratio of the real price of copper to the real price of aluminium.
20. Pratio -1	

9.6 Model Results - Total Scrap Demand

Two additive modelling methodologies were adopted; in the first, forward causal models were constructed by adding variables to models already determined as being significant, while in the second method, backward causal models were obtained by removing non-significant variables from an initial model including all the variables in Table 9.2. Multiplicative or complex causal models were not found to be more applicable than the simpler additive causal models. The ratio of the price of copper to the price of aluminium was not found to be significant in any models and for convenience, has been excluded from the results tables.

9.6.1 Forward Causal Model Results

Forward causal models were constructed by firstly examining the correlation coefficients between the dependent variable, scrap, and the independent variables. Those independent variables with high correlation coefficients were then combined with all other independent variables to form two variable models. Models with either negligible improvement in the r^2 value or with low t-statistics for variables or with obviously incorrect correlation (i.e. positive regression coefficient when negative would be expected) are rejected. The remaining two variable models were combined with the remaining independent variables to form three variable models and the procedure repeated until no further improvement was found.

The results of the initial forward causal model runs using the variables in Table 9.2 are given by descending r^2 value as model no's 1 to 13 in Table 9.3. Many other models were constructed but were rejected for reasons given above.

	Constant	2 Sempro	3 Allsempro	4 Unallsempro	5 Price	6 % imports	7 Collcost	8 Stocks	9 Arise	10 Scrap -1	11 Sempro -1	12 Allsempro -1	13 Unallsempro -1	14 Price -1	15 % imports -1	16 Collcost -1	17 Stocks -1	18 Arise -1	r^2	F stat	D-W stat	No of Var
1	-45.18			.4562 (4.99)	.0477 (1.90)	.7209 (1.90)				.2237 (2.14)		.2176 (4.10)							.926	52.7	1.89	5
2	-16.08			.4935 (5.62)						.4179 (4.08)	.2528 (4.62)		-.4358 (-3.50)						.914	58.4	2.34	4
3	-83.55			.6001 (6.54)		.8170 (2.05)						.2674 (5.46)		.0476 (1.95)	.6139 (1.78)				.913	43.9	1.64	5
4	-67.02			.4860 (4.92)						.3586 (3.12)	.1763 (3.32)						-.0140 (-1.96)	.0637 (2.27)	.906	40.3	1.93	5
5	-71.75				.1149 (3.90)					.3394 (2.75)	.1552 (2.93)					-5.5577 (-3.38)			.888	43.7	1.90	4
6	-69.50			.4113 (4.40)						.2921 (2.21)	.1736 (3.20)				.8312 (2.11)				.888	43.8	2.29	4
7	-44.47			.4739 (4.53)						.3491 (2.87)	.1433 (2.67)							.0630 (2.11)	.888	43.8	1.83	4
8	-81.34			.4813 (4.47)		.9237 (2.05)				.3089 (2.38)	.1479 (2.75)								.887	43.3	1.90	4
9	+28.25	.1382 (2.82)						.0174 (2.15)		.5567 (6.53)									.875	53.6	2.22	3
10	+38.01				.1247 (3.47)					.4380 (2.83)	.1668 (2.84)			-.0929 (-2.24					.862	34.3	2.34	4
11	+58.27		.1390 (2.25)					.0237 (3.13)		.5632 (5.98)									.862	47.8	2.12	3
12	-13.98		.1470 (2.38)	.3198 (3.00)						.5544 (5.84)									.859	46.6	2.33	3
13	+59.25		.1981 (3.26)		.0755 (2.27)					.4141 (3.79)									.839	40.0	1.87	3
14	+27.00						8.6521 (5.54)			.6153 (5.84)	.1310 (2.90)					-9.2636 (-5.56)			.921	64.2	2.25	4

Table 9.3 - Best Model Results for Forward and Backward Causal Additive Modelling of Total Scrap Demand

Before discussing individual models, some general observations can be made.

(1) All but one model include the lagged dependent variable (Scrap-1) indicating that the adaptive expectations model is relevant to scrap demand. In all the models involving Scrap-1, its coefficient lies, as expected (section 6.4.3), in the range 0-1.

(2) All models, except one, include one of the measures of semi-production, the most common being unallsempro (unalloyed semis production). This would be expected by comparing the trends in scrap collected (Figure 5.17) and semis production (Figure 5.12) and the high correlation coefficient, r, of 0.80 between them shown in Table 9.4 below.

(3) Table 9.4 also shows high correlation coefficients between total, unalloyed and alloyed semis production, in both current and lagged form. This indicates that the effects of semis production, will be overidentified if more than one measure, either current or lagged, is included in any model. While it is possible that a model could include different measures of semis production for current and lagged values e.g. current total semis production and lagged alloyed semis production, the adaptive expectations model indicates that the coefficient of the lagged value should be negative.

(4) The models may be broken down into models which include one or more of the price variables and those which exclude any price variables. The models are:

a) Price dependent : 1, 3, 5, 10, 11,13

b) Price independent : 2, 4, 6, 7, 8, 9, 12

Table 9.4 - Correlation Coefficients, r, Between the Variables in Table 9.2

VAR 1	1.00																
VAR 2	0.80	1.00															
VAR 3	0.79	0.95	1.00														
VAR 4	0.49	0.70	0.43	1.00													
VAR 5	0.70	0.54	0.51	0.41	1.00												
VAR 6	0.43	0.20	0.40	-0.33	0.18	1.00											
VAR 7	0.21	0.12	-0.07	0.49	0.65	-0.31	1.00										
VAR 8	0.50	0.59	0.45	0.65	0.55	-0.10	0.42	1.00									
VAR 9	0.38	0.27	0.46	-0.29	0.49	0.59	-0.17	0.15	1.00								
VAR 10	0.84	0.59	0.65	0.18	0.59	0.57	0.02	0.18	0.50	1.00							
VAR 11	0.85	0.72	0.77	0.29	0.54	0.43	0.07	0.30	0.38	0.83	1.00						
VAR 12	0.84	0.70	0.81	0.16	0.51	0.54	-0.06	0.26	0.50	0.81	0.96	1.00					
VAR 13	0.58	0.50	0.41	0.49	0.43	0.05	0.36	0.27	-0.04	0.60	0.74	0.52	1.00				
VAR 14	0.57	0.30	0.38	-0.00	0.70	0.44	0.33	0.18	0.65	0.73	0.58	0.56	0.43	1.00			
VAR 15	0.45	0.34	0.49	-0.14	0.33	0.48	-0.26	0.02	0.59	0.52	0.32	0.46	-0.11	0.32	1.00		
VAR 16	0.03	-0.16	-0.19	-0.02	0.38	-0.01	0.57	-0.08	0.03	0.26	0.15	-0.01	0.47	0.65	-0.17	1.00	
VAR 17	0.41	0.34	0.33	0.21	0.33	0.10	0.24	0.05	0.16	0.50	0.58	0.46	0.65	0.55	-0.03	0.42	1.00
VAR 18	0.35	0.22	0.43	-0.35	0.37	0.61	-0.26	0.09	0.95	0.45	0.35	0.51	-0.14	0.56	0.61	-0.08	0.20
VARIABLE	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17

Selection of a model for copper scrap demand is more complex than in Chapter 7, where demand for copper goods was modelled, as the structure of the scrap demand models vary considerably. For this reason a more detailed explanation of the model selection procedure is given below.

a) Price dependent models

(1) Models (1) and (3) while having high r^2 values include combinations of activity levels (i.e. unallsempro and allsempro -1 which are unacceptable.

(2) Model (5) has good values of r^2, F-statistic and Durbin-Watson Statistic but includes current copper price and the lagged collection cost variable. While not excluding its use, the fact that these variables are included indicates either a complex model streucture or an unacceptable mixture of variables. It will be shown in the next section that the latter is more likely and this is supported by the fact that Model (10) is similar to Model (5) except that, as would be expected, lagged price replaces lagged collection costs, making this model subjectively attractive. For this reason Model (10) was selected as the price dependent model of total scrap demand.

b) Price independent models

(1) Model (2) has a high r^2 value and the highest F-statistic of all forward models and shows scrap demand as purely a function of lagged scrap demand and activity levels.

(2) All other price independent models are similar to Model (2) but are statistically less significant.

Although no definite selection of a price dependent or independent model can be made on the statistical evidence presented, it is felt that the price independent models, through the inclusion of semis production variables take into account the price elasticity of scrap demand. Reference should be made to Chapter 7 to examine the models of semis production which include price variables.

The above analysis shows that two subjectively and statistically acceptable models of scrap demand are derived by additive causal model development. They are:

Model No.2 (Table 9.3)
Total Scrap demand = −16.08 + .4179 (Scrap-1) + .2528 (Sempro-1)
+ .4935 (Unallsempro) − .4358 (Unallsempro -1)
r^2 = .914 F-stat = 58.4 D-W = 2.34

Model No.5 (Table 9.3)
Total scrap demand = 38.01 + .4380 (Scrap-1) + .1668 (Sempro-1)
+ .1247 (Price) − .0929 (Price-1)
r^2 = 0.862 F-Stat = 34.3 D-W = 2.34

The predicted and actual values using the above models are shown in Figure 9.4.

9.6.2 Backward Causal Model Results

Backward causal models are developed by producing a regression equation including all independent variables considered to affect the dependent variable and then removing statistically insignificant variables until a statistically relevant equation is produced.

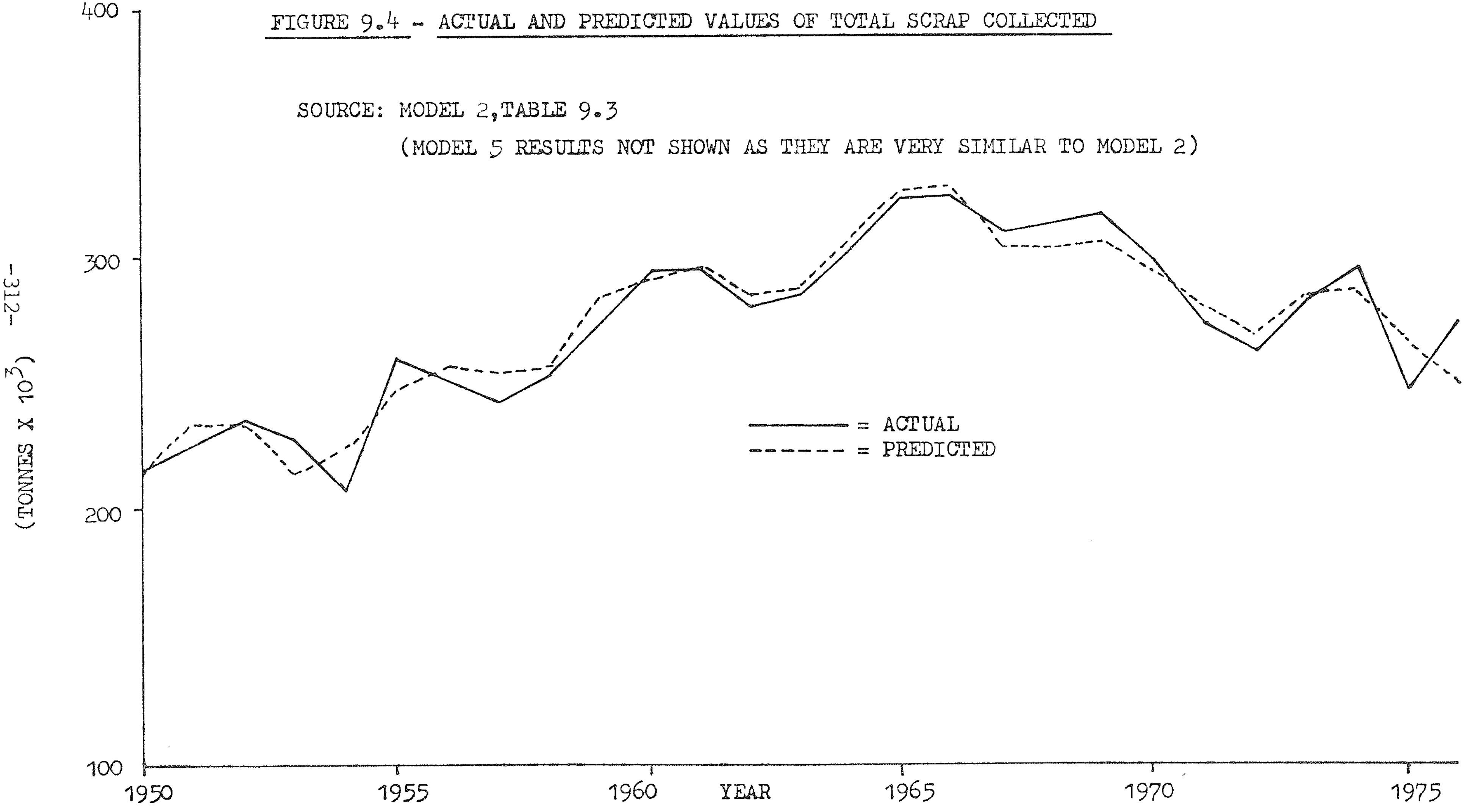
The model produced by this method from the variables listed in Table 9.2 is presented as Model (14) in Table 9.3.

The model is price dependent and is very similar to Models (5) selected in the forward modelling procedure. Model (14) has a higher r^2 value (.921); a higher F-statistic (64.24) but a slightly worse D-W statistic (2.25). The latter is counterbalanced by the models logical structure with:

Model No.14 (Table 9.3)
Scrap demand = 27.00 + .6153 (Scrap -1) + .1310 (Sempro -1)
+ 8.6521 (Collcost) − 9.2636 (Coll cost -1)
r^2 = .921 F-statistic = 64.24 D-W = 2.25.

FIGURE 9.4 - ACTUAL AND PREDICTED VALUES OF TOTAL SCRAP COLLECTED

SOURCE: MODEL 2, TABLE 9.3
(MODEL 5 RESULTS NOT SHOWN AS THEY ARE VERY SIMILAR TO MODEL 2)



The model suggests that scrap demand is dependent upon lagged scrap demand, according to the adaptive expectations model put forward in Chapter 7. The inclusion of Sempro -1 would seem to indicate both that new scrap generation, measured by this variable, is an important aspect of scrap demand and also that, as would be expected, the level of semi's production affects scrap demand. Old scrap supply is accounted for by the current and lagged values of collection costs. Difficulties in forecasting collection costs, a prime consideration in model selection, means that this model is of limited use. A close correlation between collection cost and the more readily forecast copper price (r=0.65) indicates that Model (10) is more acceptable than Model (14).

9.7 Model Results - The Consumption of Scrap by the Secondary Refiners

Forward causal additive models were constructed for the consumption of scrap by the semi-manufacturers which, as explained earlier, is assumed to equal the production of secondary refined copper. No statistically relevant backward causal models could be constructed. As in the previous section, multiplicative or complex models did not improve on the additive model results and lags greater than one year did not prove effective.

9.7.1 Forward Causal Model Results

The three statistically relevant causal models obtained by this method are listed in Table 9.5 below. For convenience, irrelevant variables have been ommitted.

Table 9.5 - Best Model Results for Forward Causal Additive Modelling of the Consumption of Scrap by the Secondary Refiners

Model No.	Constant	4 Unallsempro	5 Price	6 % imports	9 Arise	10 Scrap -1	18 Arise -1	20 Pratio -1	r^2	F Stat	D-W Stat	No. of var.
1	-17.84	.1433 (2.14)	0.0521 (2.13)			.6929 (7.03)			0.889	61.6	1.65	3
2	12.02		0.0752 (3.7)		-0.0637 (-3.2)	.8220 (8.0)			0.908	75.6	2.11	3
3	-34.97		.0929 (5.00)	.5600 (2.63)		.7659 (9.46)	-.0703 (-4.00)	22.4263 (2.29)	0.941	67.4	2.10	5

All three models include both the lagged dependent and current copper price variables whose coefficients are of the correct sign and magnitude according to the previously described "adaptive expectations" model.

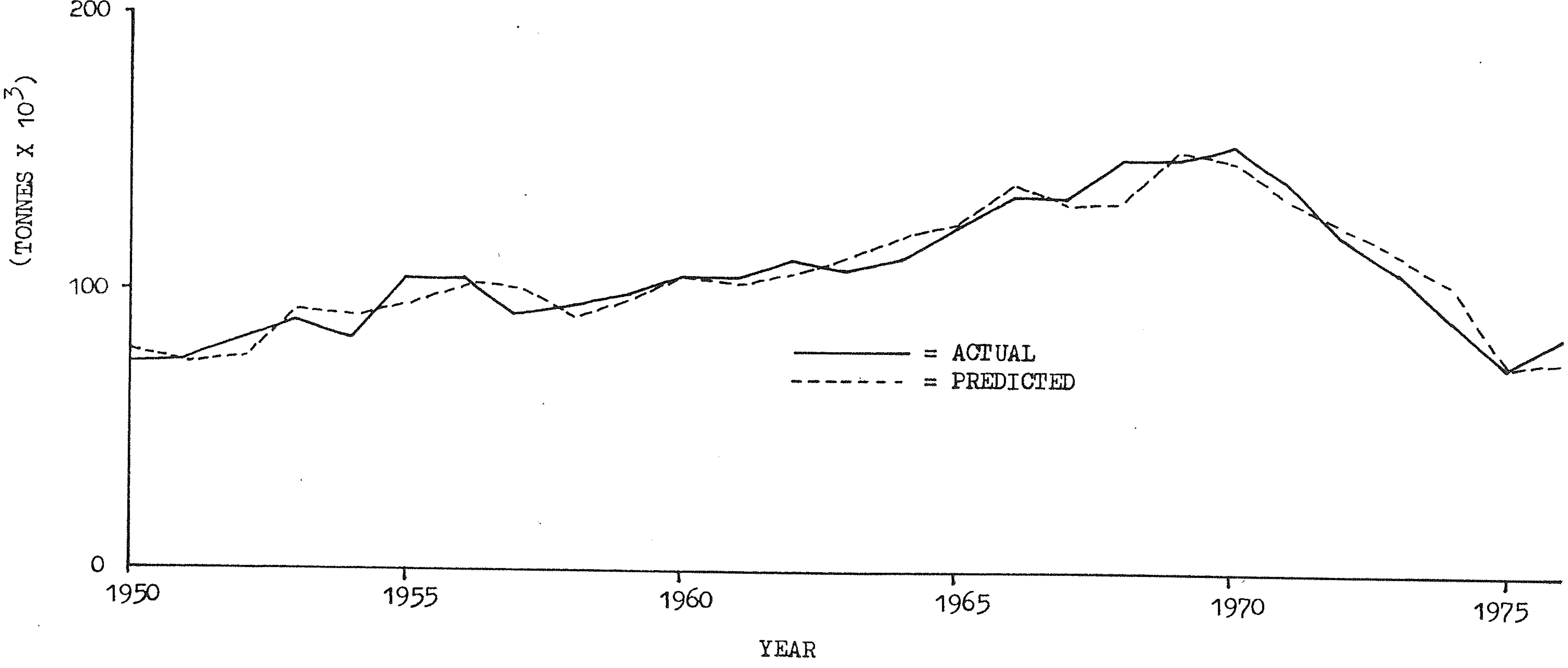
In the first model, the only other variable is the production of unalloyed semis, probably reflecting refined coppers principal market. Model (2) has a higher r^2 value and also has only one additional variable - scrap arisings. While it is possible that scrap arisings coincidentally matched the gradual decline in the secondary copper industry since 1970, the high t-values in this (and the next) model means that its importance cannot be ignored.

The lagged value of scrap arisings also occurs in Model (3) along with current price and refined copper imports and lagged price ratio. Model 3 is statistically attractive, but the positive coefficient of the percentage of UK refined supplies from nett imports of refined copper needs explaining. The sign of this coefficient implies that, as imports rise, the production of secondary refined copper also rises. The only way in which this can occur (section 5.3.2) is if the balancing figure, the production of primary refined copper, decreases, a trend identified in Section 5.7.1. Other coefficient signs are as would be expected; in particular the negative coefficient for lagged scrap arisings is pleasing as it reflects the adaptive expectations model described in Chapter 7.

Although Model (3) involves five variables, the high r^2 value, high significant F-test and a Durbin-Watson statistic of 2.10 make this model extremely attractive. Figure 9.5 shows actual and predicted values using this model.

FIGURE 9.5 - ACTUAL AND PREDICTED VALUES OF THE CONSUMPTION OF SCRAP BY THE SECONDARY REFINERS

SOURCE: MODEL 3, TABLE 9.5



9.8 Model Results - The Direct Use of Scrap

Forward and backward additive causal models were constructed for the final measure of scrap demand to be considered - the direct use of scrap. Multiplicative and complex models and lags greater than one year did not improve on the models given below.

9.8.1 Forward Causal Model Results

The three statistically relevant models obtained by forward causal modelling methods are given in Table 9.6. For convenience, irrelevant variables have been omitted.

Modelling of the direct use of scrap proved not to be as successful as for other scrap measures. This may be due to the artificial value of the statistics for the direct use of scrap noted in Section 5.7.4 and it is interesting that all three models include a stock change variable which could act as a buffer between the calculated and actual figures.

Deciding on the best model of the direct use of scrap is difficult - all three models have similar r^2, F-statistic and Durbin-Watson statistic values. Model (2) suggests, contrary to previous models, that the direct use of scrap is independent of semis production levels and last years scrap consumption and for this reason is discarded. Model (1) was selected in preference to Model (3) due to its higher r^2 value and actual and predicted values are shown in Figure 9.6.

9.8.2 Backward Causal Model Results

Model 4 in Table 9.6 shows the result of the backward causal modelling of the direct use of scrap. The high number of variables used and the inclusion of current unalloyed semis production and lagged alloyed semis production makes this model unattractive.

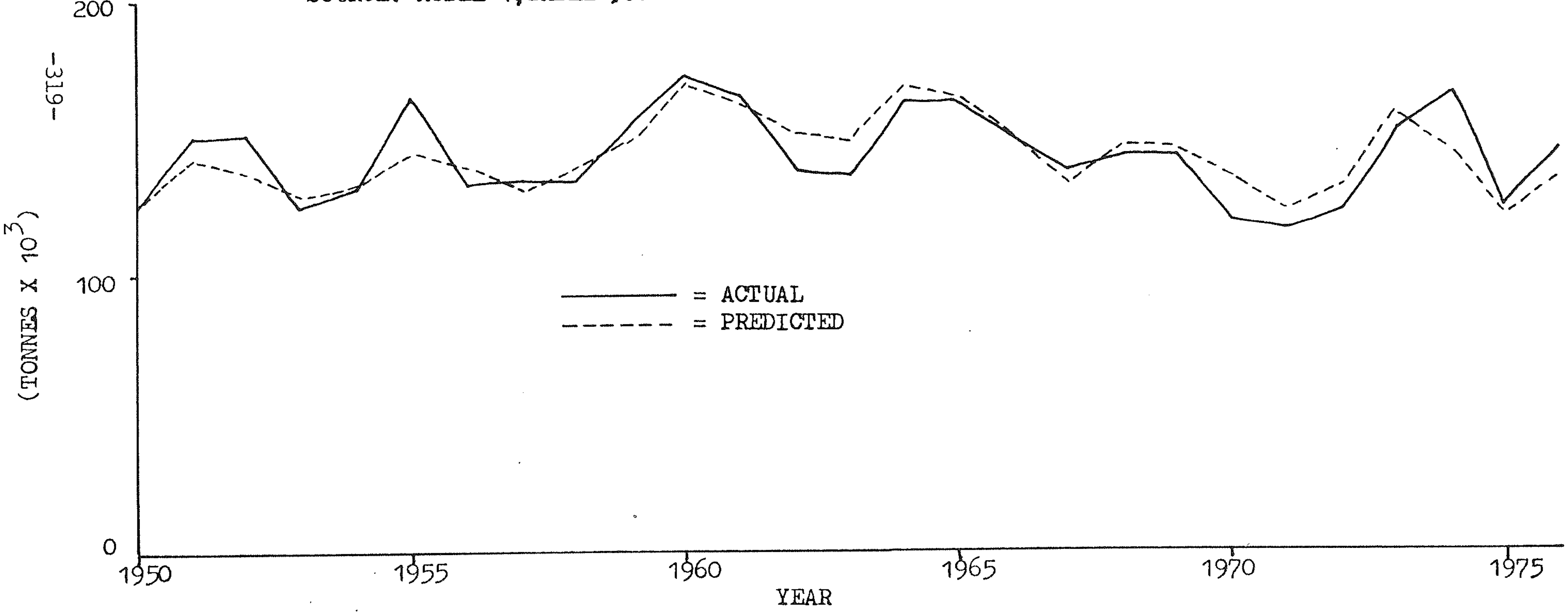
Table 9.6 - Best Model Results for Forward and Backward Causal Additive Modelling of the Direct

Use of Scrap

	Model No	Constant	4 Unallsempro	5 Price	6 % imports	8 Stocks	10 Scrap -1	12 Allsempro -1	14 Price -1	16 Collcost -1	17 Stocks -1	18 Arise -1	r^2	F Stat	D-W Stat	No. of var.
FORWAR MODELS	1	63.12	.2183 (2.34)			.0137 (2.12)	.3302 (2.84)			-4.0000 (-3.27)			.705	13.13	1.64	4
	2	126.83			.5523 (1.93)	.0309 (6.07)			-.1126 (-4.6)		.0223 (3.74)		.694	12.46	1.78	4
	3	99.65				.0283 (5.41)	.3823 (3.26)		-.0629 (-3.29)				.645	13.92	2.31	3
Backward Models	4	-40.07	.4978 (5.79)	-.1453 (-3.63)				.1314 (3.33)	-.0815 (-3.16)			.1228 (4.14)	.793	12.78	1.71	6

FIGURE 9.6 - ACTUAL AND PREDICTED VALUES OF THE DIRECT USE OF SCRAP

SOURCE: MODEL 1, TABLE 9.6



9.9 Discussion of Model Results

The recommended models of the three measures of scrap demand are given in Table 9.7. A price dependent and independent model are presented for total scrap collected as no conclusion was reached upon the acceptability of a single model in Section 9.6.

All four models are statistically acceptable and have r^2 values which compare extremely well with the U.S. models described in Section 9.3. The highest and lowest r^2 values are found in the models of the production of secondary refined copper ($r^2 = 0.941$) and the direct use of scrap ($r^2 = .705$) respectively. The model of total demand have high r^2 values of 0.914 and 0.862.

The four models all involve four independent variables; the only common variable to all three being the dependent variable lagged by one year.

The models of total demand and the direct use of scrap include a measure of semis production, but the model of the production of secondary refined copper is independent of any activity level. The problems of correlation between current and lagged value of, and between, semis production levels means that models involving more than one measure are unlikely. It may be argued that the high correlation between semis production variables and the lagged dependent variable means that the latter variable serves a dual purpose - both as part of an adaptive expectations model (supported by a coefficient value in all three models between 0 and +1) and as a measure of one of the semis production levels.

The models of total copper scrap demand are divided into price dependent models. Both are a function of the lagged dependent variable with a speed of adjustment factor of 0.56 and 0.58 respectively.

Table 9.7 - Summary of Scrap Modelling Results

Dependent variable	Constant	4 Unallsempro	5 Price	6 % imports	8 Stocks	10 Scrap -1	11 Sempro -1	13 Unallsempro -1	14 Price -1	16 Collcost -1	18 Arise -1	20 Pratio -1	r^2	F stat	D-W stat	No of Var
TOTAL SCRAP COLLECTED	a) -16.08	.4935 (5.62)				.4179 (4.08)	.2528 (4.62)	-.4358 (-3.50)					.914	58.4	2.34	4
	b) 38.01		.1247 (3.47)			.4380 (2.83)	.1668 (2.84)		-.0929 (-2.24)				.862	34.3	2.34	4
PRODUCTION OF SECONDARY REFINED COPPER	-34.97		.0929 (5.00)	.5600 (2.63)		.7659 (9.46)					-.0703 (-4.00)	22.4263 (2.29)	.941	67.73	2.10	5
DIRECT USE OF SCRAP	63.12	.2183 (2.34)			.0137 (2.12)	.3302 (2.84)				-4.000 (-3.27)			.705	13.13	1.64	4

Total semis production lagged by one year is included in both models. This variable serves a dual purpose in the price dependent model: firstly, semis production reflects demand for copper goods and secondly, it represents in lieu of more accurate information, new scrap generation. The balance between the two and the possibly greater importance of new scrap generation may have resulted in the one year lag. This is in contrast to the price independent model and the model of the direct use of scrap where current and lagged unalloyed semis production are included. No explanation for the difference can be given, but is an area for potential future investigation.

The price dependent model of total scrap demand includes the current and lagged price of copper. While not as statistically significant as the rejected model which included collection costs, this model is subjectively more attractive. No conclusion about the price elasticity of total scrap demand can be reached as arguments for and against the price dependent and independent models can be put forward.

The model of the production of secondary refined copper (for convenience termed secondary refining) is surprisingly good, with an r^2 value of 0.941 and a Durbin-Watson statistic of 2.10. The model includes the following variables:

1) The lagged dependent variable - the particular importance of this variable in this model is explained by the short-term stability of the dependent variable, resulting in a high correlation with the lagged value.

2) The price of copper - as would be expected the deflated price of copper is positively correlated to the dependent variable. This is the only scrap model which includes a direct measure of copper prices.

3) The percentage of UK imports from nett imports of copper - The effect of this variable has already been discussed (Section 9.4.5).

4) Scrap arisings lagged by one year - scrap arisings only occur in this model and may be co-incidental with, or the cause of, a gradual decline in the secondary refining industry. Depending upon the assumptions used to determine scrap arisings a case could be made for the former argument. This is supported by the negative coefficient for this variable which implies that increases in scrap arisings result in a decrease in secondary refining i.e. an opposite effect to that expected. Alternatively, if the sign convention and lagging effect are assumed to be correct, then high scrap arisings last year may have prompted the direct scrap users to increase their utilisation of old scrap, a trend which may carry over into the current year.

5) The relationship between copper and aluminium prices lagged by one year - intended as a measure of the extent to which copper is recovered along with other metals this variable is positively correlated with secondary refining effort. This implies that as coppers price rise relative to aluminiums then more recovery effort is devoted to copper. The one year lag and the correlation between real copper prices and the price ratio means that the current value of the price ratio would be closely correlated to the more relevant current real copper price and so the lagged value of the price ratio is found.

The model of the direct use of scrap is a function of:

1) The activity level of the major market for both primary and secondary copper - the unalloyed semi manufacturers. It may be argued that the stability of alloyed semis production led to its exclusion from the model.

2) The lagged dependent variable, as described above.

3) The size of stock changes which will mask true demand.

4) Collection costs lagged by one year.

A current collection costs variable was unexpectedly not included, but the inclusion of this variable in a highly significant model of total scrap demand indicates that a model of a more accurate time series for the direct use of scrap (see section 5.7.4) would include the current value of collection costs. Alternatively lagged collection costs may relate to the current availability of copper scrap due to recovery efforts in the previous year. If collection costs were high in the previous year then a large amount of the scrap arisings in that year would be available for collection in the current year. If collection costs were low in the previous year, less scrap would be available in the current year. The decision as to which is the correct explanation of the inclusion of lagged collection costs is difficult because of the uncertainty of the data on the direct use of scrap and this, together with the problems of forecasting collection costs discussed earlier, means that such a decision will not be made here.

9.10 Summary to Chapter 9

After examining the various measures of scrap demand available, the various factors which could affect scrap demand were analysed and successful models were constructed for total scrap demand, the consumption of scrap by the semi-manufacturers and the direct use of scrap. Alternative, price dependent and price independent, models of total scrap demand were constructed but no conclusion was reached on the price elasticity of scrap demand.

The modelling of copper scrap was found to be a complex process and no simple solutions are available. While the models developed are good, potential for improvement does exist by trimming of the variables and a closer examination of those years where the models are less successful. Limitations on available time means that this work cannot be carried out but it is felt that the models developed provide a sound basis for forecasting future demand for copper scrap and this will be carried out in Chapter 10.

CHAPTER 10 - FORECASTING UK DEMAND FOR COPPER GOODS AND THE SUPPLY AND DEMAND FOR COPPER SCRAP

10.1 Introduction

Models of UK copper goods demand and the supply and demand for copper scrap were developed in Chapters 7, 8 and 9. The models developed are now used to forecast these variables to the end of the century.

Future copper scrap supply and demand forecasts under various growth scenarios will be used to determine potential imbalances and to estimate the size and implications of any necessary capital investment. The policies necessary to achieve the targets identified in this Chapter will be examined in Chapter 11.

10.2 Forecasting UK Copper Semis Consumption

Forecasts of the demand for copper goods in the UK are necessary to determine the future size of the UK copper industry. Additionally these variables will be used in the models of scrap supply (developed in Chapter 8) and scrap demand (developed in Chapter 9).

Debate upon the ability of quantitative modelling techniques to forecast the supply, demand and price of copper has continued for many years. This is because future demand will depend upon a wide range of social, political and economic factors - for example, the rate of economic growth, dislocations in growth between countries, the relative price of copper and alulminium - that relatively precise forecasts in the near future are difficult and forecasts beyond the year 2000 little more than exercises in computer programming. For this reason the time horizon chosen for forecasting is the year 2000.

Simple extrapolation of recent historic trends in total UK semis consumption (Figure 5.12) indicates that consumption in the year 2000 will be 50% below that for 1976. This contrasts strongly with the long term trend which suggests a 30% growth over the same period.

An alternative forecasting method is to estimate demand for each of the major end-uses identified in Section 4.3 by relating demand for that end-use to appropriate economic indicators. This method has the advantage of allowing for technological changes and other factors and is used extensively by the US Bureau of Mines (13). As discussed in Section 4.3 the unavailability of sufficiently detailed statistics makes this type of forecast inapplicable to the UK.

In Chapter 7, statistically and subjectively acceptable models of UK demand for copper goods, measured by total, unalloyed and alloyed semis consumption, were developed, and the component independent variables are reproduced in Table 10.1. By forecasting each of the independent variables in Table 10.1 forecasts of UK semis consumption can be made. While more sophisticated than the simple extrapolation of historic trends described earlier, this method, like the US Bureau of Mines forcasts (13), is incapable of anticipating major turning points unless accurate forecasts of the independent variables can be made. In the following sections forecasts of the variables other than the lagged dependent variables listed in Table 10.1 will be made. In some cases reference to published forecasts will be made, while in other cases extrapolation of historic trends will be used.

10.2.1 Index of Industrial Production (all industries)

The inclusion of the index of industrial production in the model of copper goods demand allows for the economic growth of the UK. Historically, the UK index of industrial production grew at +2.2% per annum over the period 1960 - 1976 although very low growth rates of -2.8% and -4.9% per annum occurred in 1974 and 1975 after the first oil crisis.

Table 10.1 - Variables Necessary to Forecast Total, Unalloyed and Alloyed Semis Consumption (from Chapter 7)

Independent variables / Dependent variables		Lagged dependent variable	Index of industrial production (all industries)	Real price of copper (lagged by one year)	Real price of aluminium (lagged by one year)	Deflated material and fuel stock changes
1. Total Semis Consumption	a)	X	X	X	X	X
	b)	X		X	X	X
2. Unalloyed Semis Consumption	a)	X	X	X	X	X
	b)	X		X	X	X
3. Alloyed Semis Consumption		X		X	X	X

Gluschke (93) assumes a global growth rate of 3.5% over the 1977 - 90 period with alternative growth rates of 2.0% and 5.0% (or 40% about the base case). Generally (145) estimates of 1.5% long term growth rates in industrial production are accepted for the UK. To investigate the effect of economic activity upon copper goods consumption, a base case growth rate of 1.5% was assumed with extremes of 0.0% and 3.0% used to assess the sensitivity of the forecasts. The effect of using the industrial production dependent and independent models developed in Chapter 7 will also be examined.

10.2.2 The Real Price of Copper

The LME cash price of refined copper, deflated to a 1963 price by the wholesale price index for materials and fuel purchased by manufacturing industry, is included in the model specifications in Table 10.1.

Forecasting future copper prices is difficult, involving factors exogenous to the UK. Copper price models are available but are complex and instead reference has been made to published estimates. The dominance, in general economic terms and in copper consumption, of the US means that prices are forecast in US cents per lb and this practice has been continued here. A conversion factor, assuming crude values of 2.0 $/£ and 2205 lbs per tonne, has been used to convert copper prices from c/lb to £/tonne for inclusion in the model. In the rest of this Chapter, current prices mean undeflated prices and real prices indicates deflated prices.

The close relationship between ore grade and production energy costs for copper has already been discussed in Section 2.4.2. About 50% of the price of copper is due to energy costs and Chapman (33) and Slade (160) amongst others, considered the effects of declining ore grade upon copper production costs and copper prices to be significant.

The apparent trend in the energy costs of producing copper in Figure 10.1 indicates that future real copper prices will have to rise significantly unless less energy intensive processes (for example, hydrometallurgical treatment of sulphide ores (93)) are employed.

Higher real copper prices are often quoted as being incentives for substitution of aluminium for copper, and a shift towards secondary copper with a resultant overall drop in demand for primary copper. Each of these aspects will be discussed in following sections.

Slade (160) estimated 1986 current copper prices under various energy cost and ore grade scenarios as shown in Table 10.2.

Table 10.2 - 1986 Current US Producer Copper Prices, under various energy cost and ore grade scenarios, c/lb (160)

Energy costs / Ore grades	Low	Medium	High
Low		160	
Medium	145	146	148
High		134	

The effect of energy costs alone upon 1986 current copper prices is surprisingly small. Slade explains this apparent contradiction by assuming that an energy price increase reduces copper demand so slowing the drop in copper ore quality. Therefore in the long term, real mining costs are lower than if no energy price increase had occurred. This view is supported by the wider, but still narrow, variation in 1986 current copper prices with ore grade shown in Table 10.2. Whether the argument for the effect of energy costs along upon demand can also be applied to declining ore grade is debatable, but certainly the resultant increase in real price would be expected to reduce demand by an unknown amount. Between 1975 and 1977 US producer costs rose by at least 20% in current terms to an estimated 62-65 c/lb (162). A large proportion of this increase can be attributed to sharply increased energy and labour outlays and pollution control costs.

A Chase Econometric Associates report quoted in (162) estimated 1985 US current produce prices to be 160 c/lb which compares reasonably well with the 146 c/lb medium energy cost, medium ore grade forecast by Slade (Table 10.2).

The above examination of published copper price forecasts indicates a likely 1986 current copper price of 146 c/lb with possible extremes of 134 and 160 c/lb. 1986 real prices (in 1970 terms) were obtained from the 1986 current prices by applying a conservative 5% inflation rate. The resultant 1986 real prices were 67 c/lb (£741/tonne) with a range of 62 c/lb (£680/tonne) to 74 c/lb (£810/tonne). Comparison with the 1970 real price of 45 c/lb indicates that these 1986 real copper prices correspond to an average growth in real copper price to 1986 of 3.5% per annum, with a range of 2.4 to 4.4% per annum. These growth rate values have been assumed to continue to the year 2000 and have been used to construct base, low and high copper price scenarios.

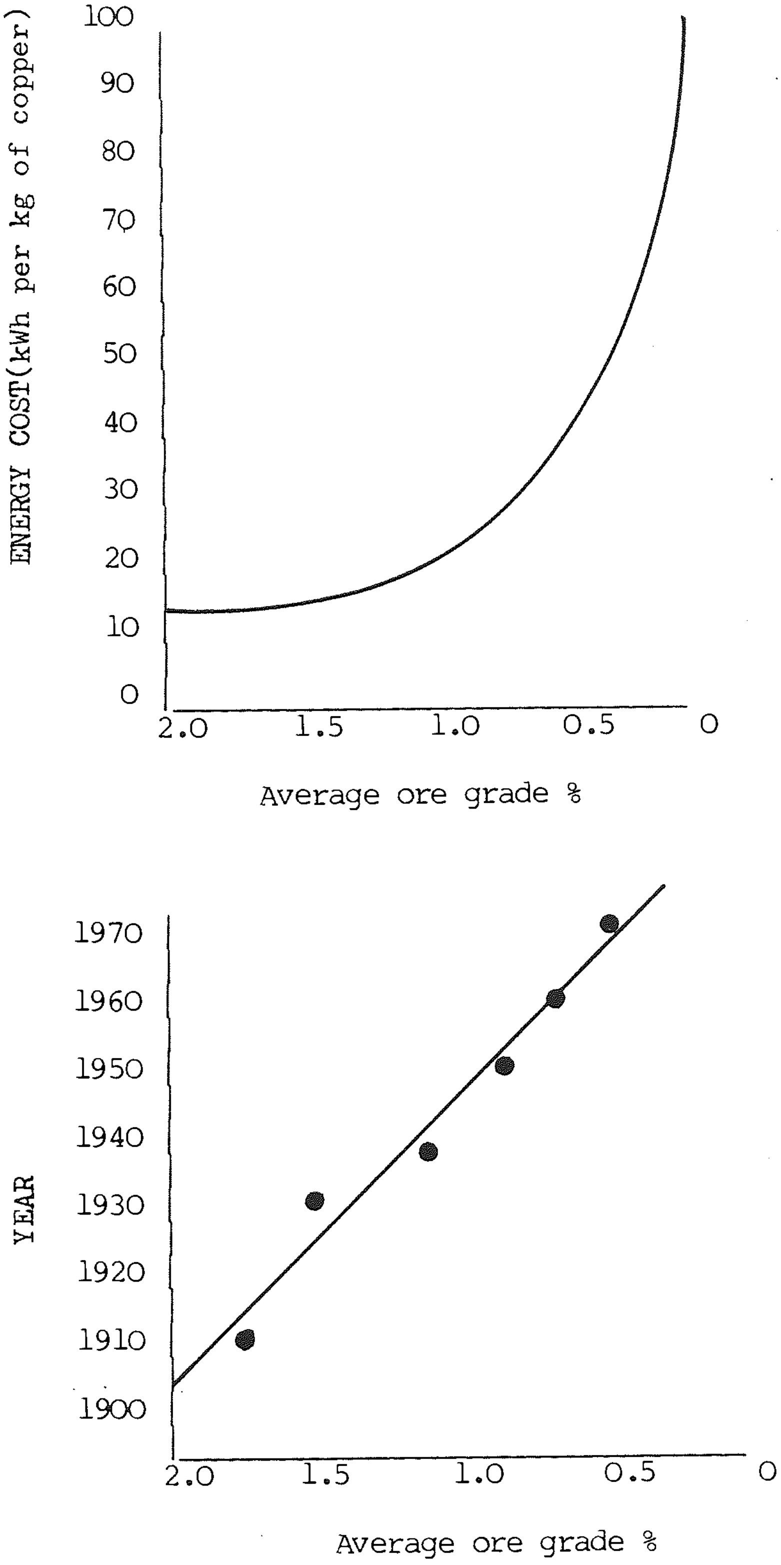


Figure 10.1 - The Effect of Declining Ore Grade Upon Energy Cost and Historical Ore-Grade Mined

(33,34,161)

10.2.3 The Real Price of Aluminium

Primary aluminium production is more energy intensive than primary copper production needing up to eight times as much energy per tonne of metal, (Chapman (33)) but aluminium ore grades are fairly constant in comparison to coppers (160). Slade (160) constructed 1986 current price estimates for aluminium under similar conditions to those described for copper in the previous section and the results are shown in Table 10.3.

Table 10.3 - 1986 Current Aluminium Prices Under Various Energy Cost and Ore Grade Scenarios, c/lb (160)

Scenario	Low	Medium	High
Energy price	88 (41)	107 (49)	141 (65)
Ore grade	170 (78)	179 (83)	189 (87)

Notes a) Figures in brackets represent 1986 current aluminium prices deflated to 1970 real prices. (see previous section).

Table 10.3 indicates that aluminium's future real price is much more uncertain than coppers, with a greater sensitivity to energy prices. No reason is given by Slade for the apparent contradiction between the two medium scenarios, but the general indication is that the 1970 aluminium price of approximately 25 c/lb (£276/tonne) will rise to an average 1986 real price of 49 c/lb (£541/tonne) with extremes of 41 (£453/tonne) and 87 c/lb (£961/tonne). These figures correspond to real growth rates of 6.0, 4.0 and 15.0% per annum and are significantly higher than for copper.

Perhaps more importantly as far as this work is concerned, the price ratio of aluminium to copper (expressed as price of aluminium/price of copper) also varies. The price ratio is an important link between aluminium and copper prices, affecting demand for both metals. A shift to a lower price ratio according to the discussion and models developed in Chapter 7 could mean greater substitution of aluminium for copper.

Over the period 1964 to 1976 the price ratio averaged 0.5 (see Figure 7.4) and, with the average low and high forecasts for the price of aluminium developed in this section, would move to 1986 values of to 0.66 (low prices), 0.77 (average prices) and 1.17 (high prices). Under all these conditions the historical trend in the substitution of aluminium for copper would be reversed, a surprising scenario against most published estimates of future substitution trends. Gluschke (93) for example, expects the existing price ratio to continue to the year 2000 or alternatively for the price ratio to decline, increasing the substitution of aluminium for copper. Warwick-Ching (163) while admitting that aluminium did make gains at the expense of copper in the late 1960's and early 1970's, agrees that the pattern of substitution has stabilised and in one or two areas aluminium has retreated.

Perhaps more importantly, other materials are competing for the market currently supplied by copper, and these materials are not included in the price ratio used. Optical fibres and plastics are expected to make inroads but the size and extent of substitution is unknown at present. To cover all possibilities and, in particular, to allow for substitution by materials other than aluminium, a base case price ratio constant at 0.5 will model the "status quo" situation, a gradually increasing price ratio from 0.5 to 0.75 by 2000 allows for a more rapid increase in the price of aluminium compared to copper and a decrease from 0.5 to 0.25 by 2000 allows for the anticipated scenario of increased substitution for copper by aluminium and other substitutes.

10.2.4 Deflated Mineral and Fuel Stock Changes

Figure 10.2 shows the three year average of UK material and fuel stock changes used to model copper goods demand in Chapter 7. A strong four year cyclical component about a mean value of +£34 million can be seen. As stock changes do not have a significant effect on copper goods demand, but build into the model a factor for business cycles, their absolute value is not essential in longer term forecasts.

In view of the above analysis, material and fuel stock changes are assumed to continue their four year cyclical trend into the future with peaks and troughs of +120 and -52 £million with intermediate year values of +34 £ million.

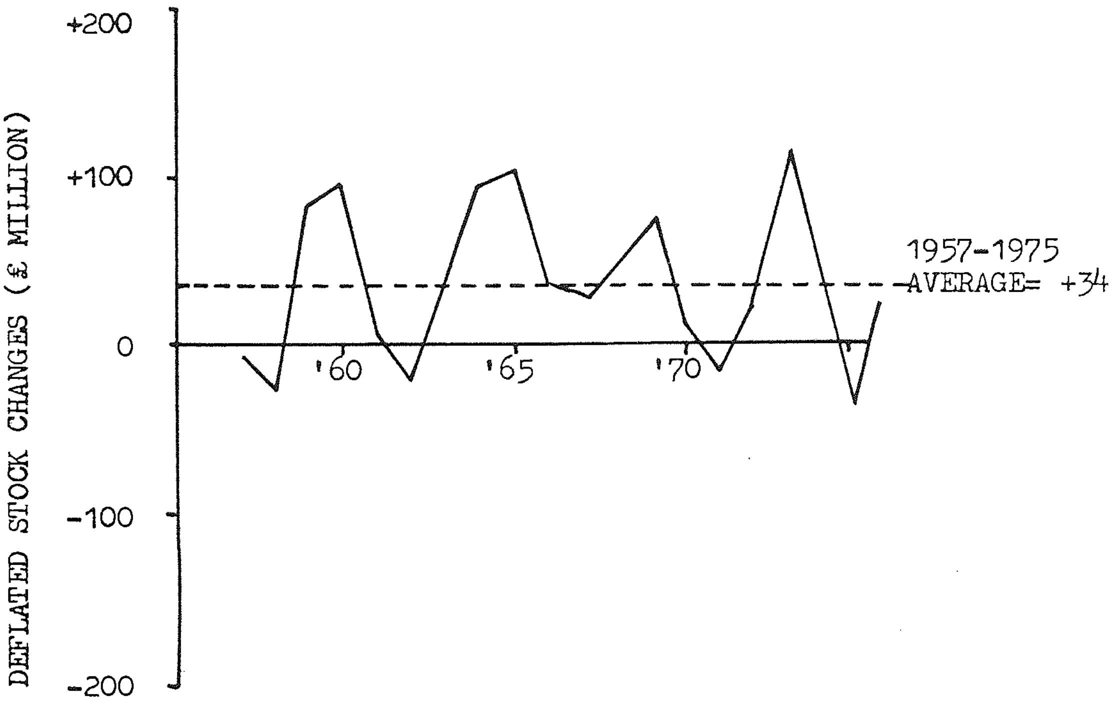


Figure 10.2 - Material and Fuel Stock Changes 1957 - 1975 (3 year average)

(1963 Prices)

10.2.5 Independent Variables Forecast Summary

a) Index of Industrial Production

Growth from 1976 value of 102 at rates of 1.5 (base case), 0.0% and 3.0% per annum.

b) The Real Price of Copper

The real price of copper has been assumed to grow from its 1976 value of £207/tonne at real growth rates of 3.5% (base case), 2.4% and 4.4% per annum.

c) The Real Price of Aluminium

The real price of aluminium will be directly linked to real copper prices so that the price ratio between the two will either grow steadily by 2000 from 0.5 to 0.75, decrease to 0.25 or stay constant over the whole period at 0.5 (base case).

d) Deflated Material and Fuel Stock Changes

Material and fuel stock changes will continue their cyclical trend with peaks and troughs of +120 and −52 £ million about a mean value of +£34 million.

10.2.6 Forecasting Results - Semis Consumption

Forecasts of total, unalloyed and alloyed semis consumption up to the year 2000, under various scenarios, using the models developed in Chapter 7 are presented in Table 10.4 and selected forecasts shown diagrammatically in Figure 10.3.

The model of total semis consumption which included industrial production gives a base case forecast (1.5% growth in industrial production, 3.5% growth in copper price and a constant copper:aluminium price ratio of 0.5) of 878,000 tonnes by the year 2000 and is very

INDUSTRIAL PRODUCTION DEPENDENT MODELS

IP / Cu	0.0%	1.5%	3.0%
2.4%	417	663	996
3.5%	362	608	941
4.4%	306	552	885

IP / Cu	0.0%	1.5%	3.0%
2.4%	632	878	1211
3.5%	632	878	1211
4.4%	632	878	1211

IP / Cu	0.0%	1.5%	3.0%
2.4%	846	1092	1425
3.5%	902	1148	1480
4.4%	957	1203	1536

Total Semis Consumption (Section 7.4.4)

IP / Cu	0.0%	1.5%	3.0%
2.4%	248	445	708
3.5%	199	396	659
4.4%	151	348	611

Cu:Al varies; 0.5-0.25

IP / Cu	0.0%	1.5%	3.0%
2.4%	416	613	876
3.5%	409	606	869
4.4%	403	599	862

Cu:Al varies; 0.5 - 0.5

IP / Cu	0.0%	1.5%	3.0%
2.4%	585	781	1044
3.5%	620	816	1079
4.4%	654	851	1114

Cu:Al varies; 0.5 - 0.75

Unalloyed Semis Consumption (Section 7.4.2)

INDUSTRIAL PRODUCTION
INDEPENDENT MODELS

Cu:Al / Cu	0.5 -0.25	0.5	0.5 -0.75
2.4%	471	620	769
3.5%	421	610	799
4.4%	372	601	830

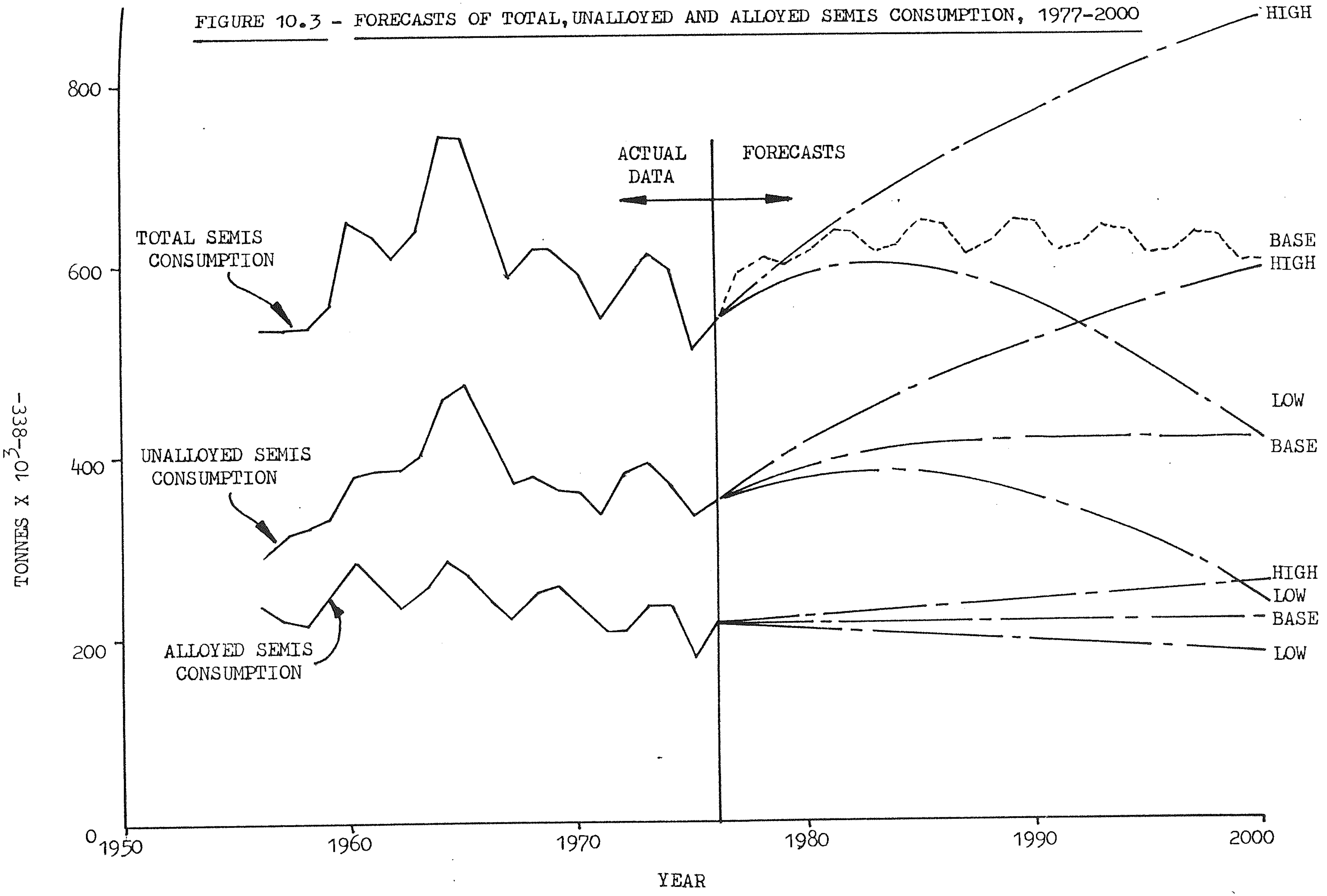
Cu/Al / Cu	0.5 -0.25	0.5	0.5 -0.75
2.4%	290	399	507
3.5%	251	388	525
4.4%	211	377	544

Cu/Al / Cu	0.5 -0.25	0.5	0.5 -0.75
2.4%	183	220	256
3.5%	183	230	276
4.4%	183	240	297

Alloyed Semis Consumption (Section 7.4.3

Table 10.4 - Forecasts of Copper Semis Consumption in the Year 2000 under Alternative Industrial Production Growth Rate (IP), Copper Price Growth Rate (Cu) and Copper:Aluminium Price Ratio (Cu:Al) Scenarios (tonnes x 10^3)

FIGURE 10.3 - FORECASTS OF TOTAL, UNALLOYED AND ALLOYED SEMIS CONSUMPTION, 1977-2000



sensitive to alternative industrial production growth rates. Forecasts varied from 632,000 tonnes (0% annual growth in industrial production) to 1,211,000 tonnes (3% annual growth in industrial production) or -28% or +38% compared to the base case.

The model coefficients for the prices of copper and aluminium mean that, at a constant price ratio of 0.5, changes in copper price growth rates have no effect on total semis consumption forecasts which then becomes purely a function of industrial production with a superimposed cyclical component induced by stock changes (see Figure 10.3). For convenience, the cyclical component is only shown for the base case.

The models which include the industrial production variable result in unreasonable forecasts when historical trends are examined. In contrast, the models developed in Chapter 7 for more recent years, which do not include the industrial production variable, show a lower and narrower band of forecasts (Table 10.4) for a constant copper:aluminium price ratio. Forecasts vary by 1-2% compared to the base case forecast for 2000 of 610,000 tonnes.

Varying the copper:aluminium price ratio to 0.75 or 0.25 by the year 2000 increases or decreases copper semis consumption by 25% compared to the base case forecast. While it is expected (section 10.2.3) that the price ratio will decrease over the next 25 years. These scenarios result in a 30% decrease or increase in total semis consumption compared to the base case for both the industrial production independent and dependent models.

An alternative to using the forecasts of total semis consumption described above is to summate the forecasts of unalloyed and alloyed semis consumption given in Table 10.4. No significant variations from the total semis consumption forecasts are found, although a slightly lower growth rate occurs. This has been assumed to support the validity of the models used.

Individually, unalloyed semis consumption shows similar, but less severe, growth than total semis consumption while alloyed semis consumption remains stable at 220,000 tonne/annum for the base case and shows only marginal growth for the low and high scenarios.

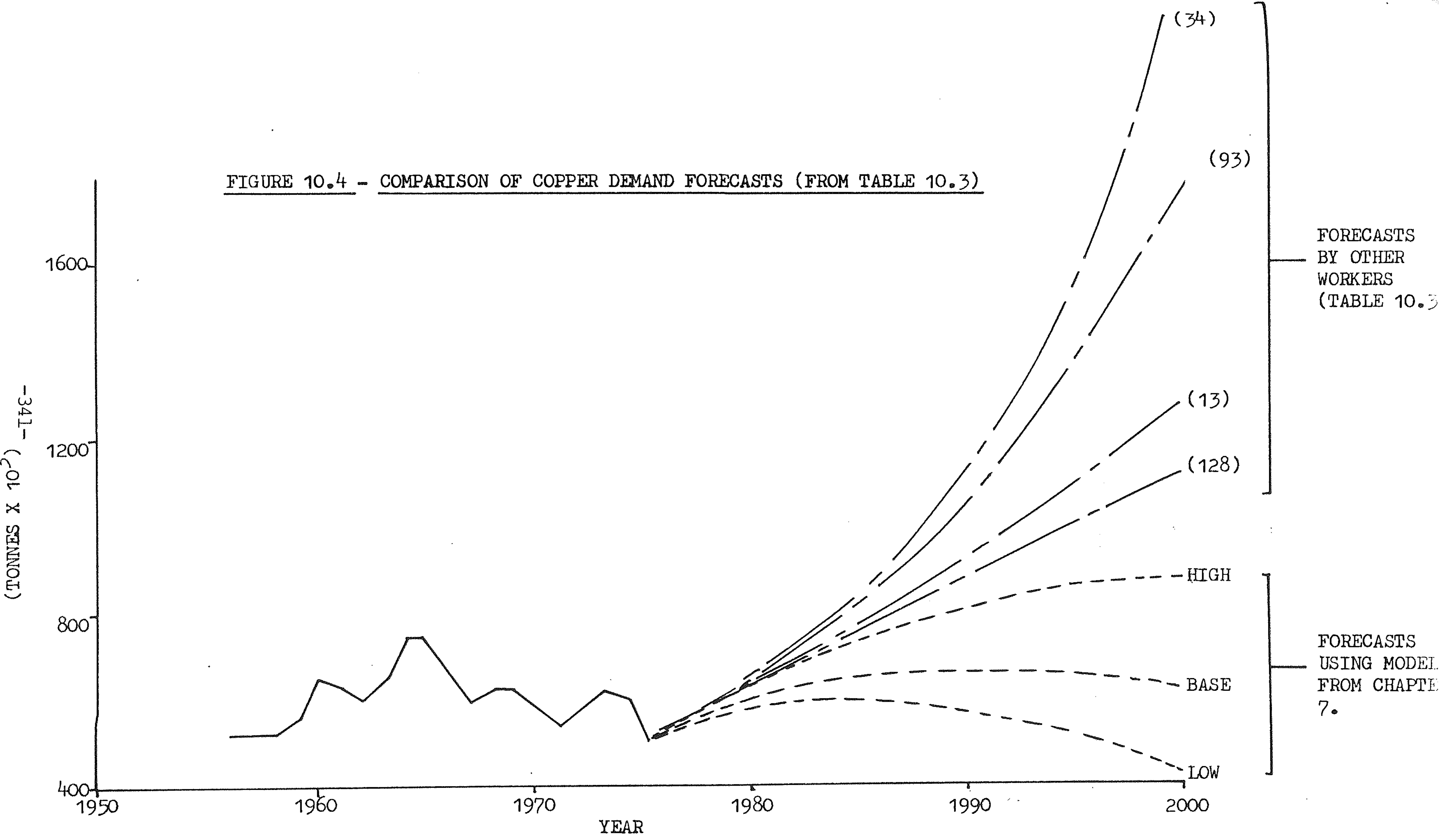
The high, base and low forecasts of copper demand selected in Table 10.4 and shown in Figure 10.3 were made principally to investigate the effect of these scenarios upon scrap supply and demand. The range of scenarios selected is therefore arbitrary, but is designed to reflect the conclusions reached in Chapter 7, that a break from the historic link between copper demand and industrial production has occurred. The more probable low and base scenarios use the industrial production independent model while the more unlikely high scenario uses the mean of the industrial production dependent models.

The annual rate of growth in copper semis consumption under base, low and high growth forecasts is shown in Table 10.5 and Figure 10.4 together with other published estimates.

Table 10.5 - Comparison of Copper Demand Forecasts and Other Published Estimates

Source	Year	Growth rate (%/annum)			Region covered
		Low	Medium	High	
Models developed in this section	1976	-0.9	+0.5	+2.5	UK
Gluscke (93)	1977		5		developed economies
Govett+Govett(34)	1976		6		World
Mineral Facts (13)	1970		3.4		US
Mineral Facts (13)	1975	3.5	3.6	3.7	US
Wimpfen (164)	1975	4.0			US
Malenbaum (128)	1973		2.9		US

FIGURE 10.4 - COMPARISON OF COPPER DEMAND FORECASTS (FROM TABLE 10.3)



It is apparent that the copper demand forecasts developed for the UK in this section are well below other published estimates. These other estimates are, in the majority, based on econometric models involving an industrial production index. This has already been shown to be an unreasonable assumption for the UK over recent years and this view is supported by the unrealistic demand forecasts observed in Figure 10.4 at growth rates greater than say 2.5% per annum. While the forecasts produced using an industrial production index are probably suitable for the developing countries where industrial growth will induce a demand for electrical transmission equipment, telecommunications and other electrical goods, the analysis presented in Chapter 7 and this section indicates that a saturation level has been reached in the UK and only replacement equipment is required for obsolete goods. It will be interesting to monitor copper demand over the next decade to observe whether this assumption is correct.

Trends in the end-uses of copper semis after fabrication were described in Section 4.3 where it was concluded that determining future end-uses was beyond the scope of this project. Gluschke (93) however, quotes a Commodities Research Unit report which projected end-use trends for developed market economics. These projections are presented in Table 10.6.

Table 10.6 - Projected End-Uses in Developed Market Economies, %, 1980 - 1990 (93)

End-use	Electrical	Construction	General Engineering	Transport	Domestic
Chapter 4 estimate	52	19	15	12	3
1980 1985 1990	49.5 48.3 47.1	15.0 15.3 15.6	16.4 16.8 17.2	11.8 12.1 12.5	7.4 7.7 8.0

The end-use estimates for 1980 are broadly compatable with those developed in Chapter 4. Electrical end-uses over the 1980-1990 period are shown as declining, reflecting an anticipated slow down in the growth of electricity consumption as saturation is reached (see Section 2.6.3) and only replacement equipment is demanded. Each of the other end-use categories is expected to marginally increase its share of total consumption.

10.2.7 Discussion of Forecast Results and Their Effect on Copper Scrap

The above analysis of future UK semis consumption forecasts shows that the low, base and high growth scenarios selected are lower than other published estimates and that UK copper demand is probably independent of industrial production. Overall, UK copper demand is expected to decline as substitutes other than aluminium offset copper demand. Extrapolation of historic trends indicates that this is not an unreasonable assumption.

The existence of possible future turning points in either copper prices or copper substitute prices cannot be ruled out. For example, a long term recession could have a significant impact on the forecasts in Table 10.4, as could a significant rise in energy costs on copper prices. But perhaps the most likely variance to historic trends is the development of new substitutes and economies of use for copper.

Historically, aluminium has been the major substitute, but newer materials such as optical fibres or plastics may become significant. The future impact of these materials on copper consumption is very difficult to model using the methodology in Chapter 7 and limits discussion to a qualitative assessment. The only signficant inroad made by plastics is for car radiators and optical fibres have only been used so far in minor applications, but are likely to account for a rising proportion of both telecommunications (mainly for high density trunk lines) and cable and wiring in motor cars. It is too early to determine the likely market penetration by optical fibres, although more definite indications should become apparent over the next few years. The only estimates available for the UK is an arbitrary market penetration figure of up to 10,000 tonnes/year copper equivalent (or 2% of 1976 demand) made by Tron (157).

In contrast, the development of a mass produced road passenger electric car with an estimated copper content (163) of 100-200 lb (45 - 90 kg) of copper per vehicle compared to 15lb (7 kg) at present for a small petrol engined car, would open up new markets for copper. The conversion of all existing petrol vehicles to electrical would create a demand for up to 100,000 tonnes of copper. Development of electric vehicles is, however, unlikely until the 1990's.

Economies of use for copper are difficult to identify but a good example is in car radiators where competition from aluminium and plastics has resulted in the development of thin strip and thinner walled tube. This trend could have a significant impact on scrap availability (see Section 10.4) and the resulting lower copper content of certain items may make recovery difficult and require the development of new recycling technology.

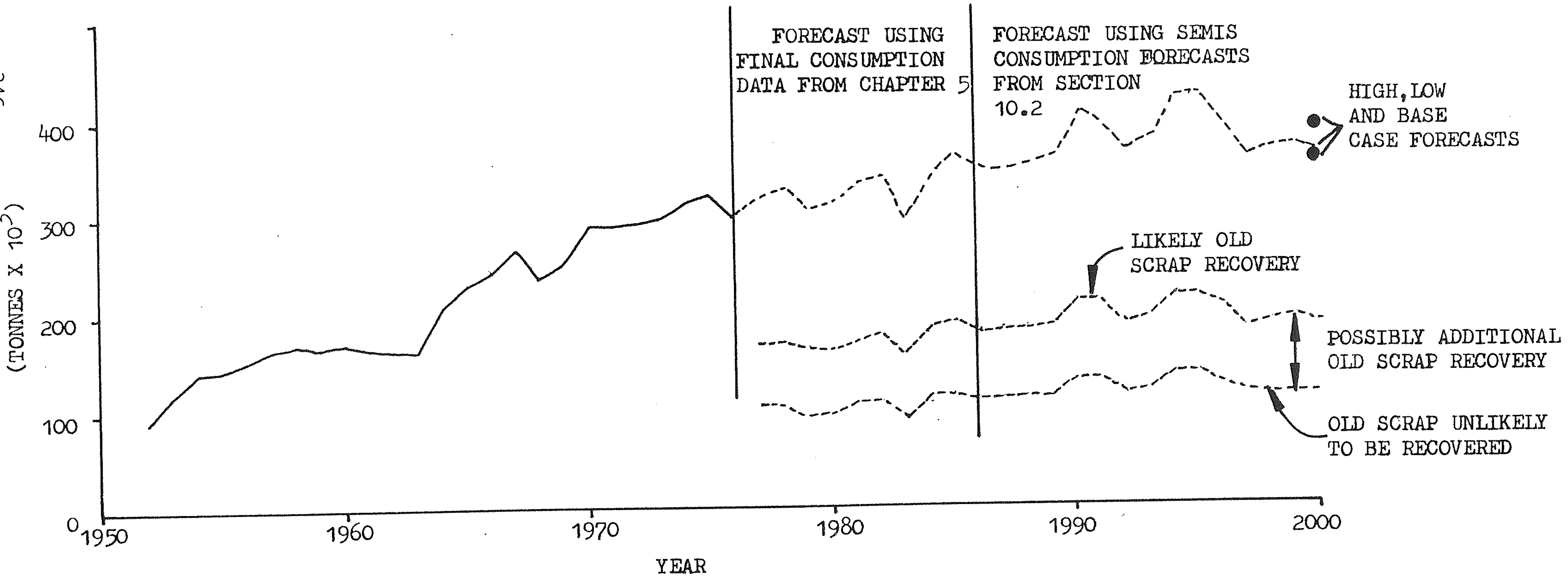
In conclusion, lack of detailed information means that future subsitution for copper by other materials is difficult to model quantitatively. Optical fibres and plastics are likely to make inroads but the copper fabricators may be able to compete by economising in copper usage in threatened goods. Overall, copper demand is expected to remain at its current level or decline over the next twenty years.

10.3 Forecasting Future U.K. Scrap Supplies

In Chapter 8 the mechanism of estimating annual potentially recoverable scrap arisings was described together with the meaning and determination of the size of the semi-permanent pool of potentially recoverable scrap. Only old scrap supply will be discussed here, forecasts of annual potentially recoverable scrap arisings can be made using the total semis consumption data developed in Section 10.2. This is achieved by allowing for an average fabrication efficiency of 71.4% (Table 5.10) and a nett export of fabricaed goods of 10% (Section 5.3.4). The appropriate fraction of the resultant final consumption of copper goods after allowing for 5% dissipative uses is then lagged by the relevant lifetime to give the annual potentially recoverable scrap arisings. This analysis also enables new scrap generation to be calculated as 28.6% of semis consumption, and this will be used in Section 10.4 to calculate future old scrap withdrawals for comparison with the annual potentially recoverable scrap arisings developed in this section.

The results of the calculations described above are shown in Figure 10.5 for the years 1977-2000, where a historic steady upward trend appears to be flattening out. The forecast of scrap arisings shown is for the base case forecast of total semis consumption. As 70% of arisings in any year were consumed 30 years ago (Table 8.3), scrap arisings shown prior to 1987 are independent of these forecasts and those after 1986 are still largely independent of the semis consumption forecasts. This is demonstrated by the similarity between post 1986 forecasts using the low, base and high growth forecasts of semis consumption. For ease of interpretation only the 2000 estimates of scrap arisings for the low and high growth scenarios have been shown.

FIGURE 10.5 - FORECASTS OF OLD COPPER SCRAP SUPPLY



The forecasts of annual potentially recoverable scrap arisings will, as discussed above, be used in the next section on future scrap demand to determine if any imbalances between scrap supply and demand can be identified. Figure 10.6 shows a breakdown of annual scrap arisings broken down into the copper scrap which is likely to be recovered (=recoverability factor) and that which is not normally recovered. Of the latter category, a modified Battelle estimate indicates that an additional 67% could be recovered and that 35% is unlikely to be recovered. In the following sections, estimates of the size of the likely and possibly recoverable sections of Figure 10.6 will be made. Particular emphasis will be given to the assessment of the likely recovery of copper scrap, as any shortfall in copper scrap demand is likely to result in a potential to recover an additional volume of copper scrap from this sector.

In Chapter 8 a historic average recoverability factor, defined as the percentage of annual potentially recoverable scrap arisings actually recovered, of 52% was calculated for the period 1952-1976. As noted in Section 10.2 there will be a future trend towards miniaturised goods containing smaller amounts of copper which will probably decrease the recoverability factor. On the other hand technological advances will enable the more efficient recovery of copper scrap. By carefully examining trends in copper usage in fabricated goods it may be possible to estimate a future recoverability factor but this is beyond the scope of this project. Overall, it is felt that the recoverability factor will decrease to an unknown level as copper scrap becomes more difficult and less economic to recover. Lack of empirical data means that the historical average recoverability factor of 52% has been assumed to represent the upper limit to likely future scrap recovery levels even

Table 10.7 - Forecasts of Annual Potentially Recoverable Scrap Arisings and Likely Old Scrap Recovery Rates, 1977 - 2000

Year	Annual potentially recoverable scrap arisings, (a), tonnes 10^3	Likely old scrap recovery ((b) = (a) x 0.52))	Possible additional old scrap recovery ((c) = (a) x .32)
1977	324	168	104
1978	327	170	105
1979	303	158	97
1980	310	161	99
1981	330	172	106
1982	342	178	109
1983	294	153	94
1984	343	178	110
1985	365	190	117
1986	348	181	111
1987	347	180	111
1988	352	183	113
1989	362	188	116
1990	404	210	129
1991	397	206	127
1992	362	188	116
1993	375	195	120
1994	417	217	133
1995	422	219	135
1996	391	203	125
1997	355	185	114
1998	364	189	116
1999	370	192	118
2000	362	188	116

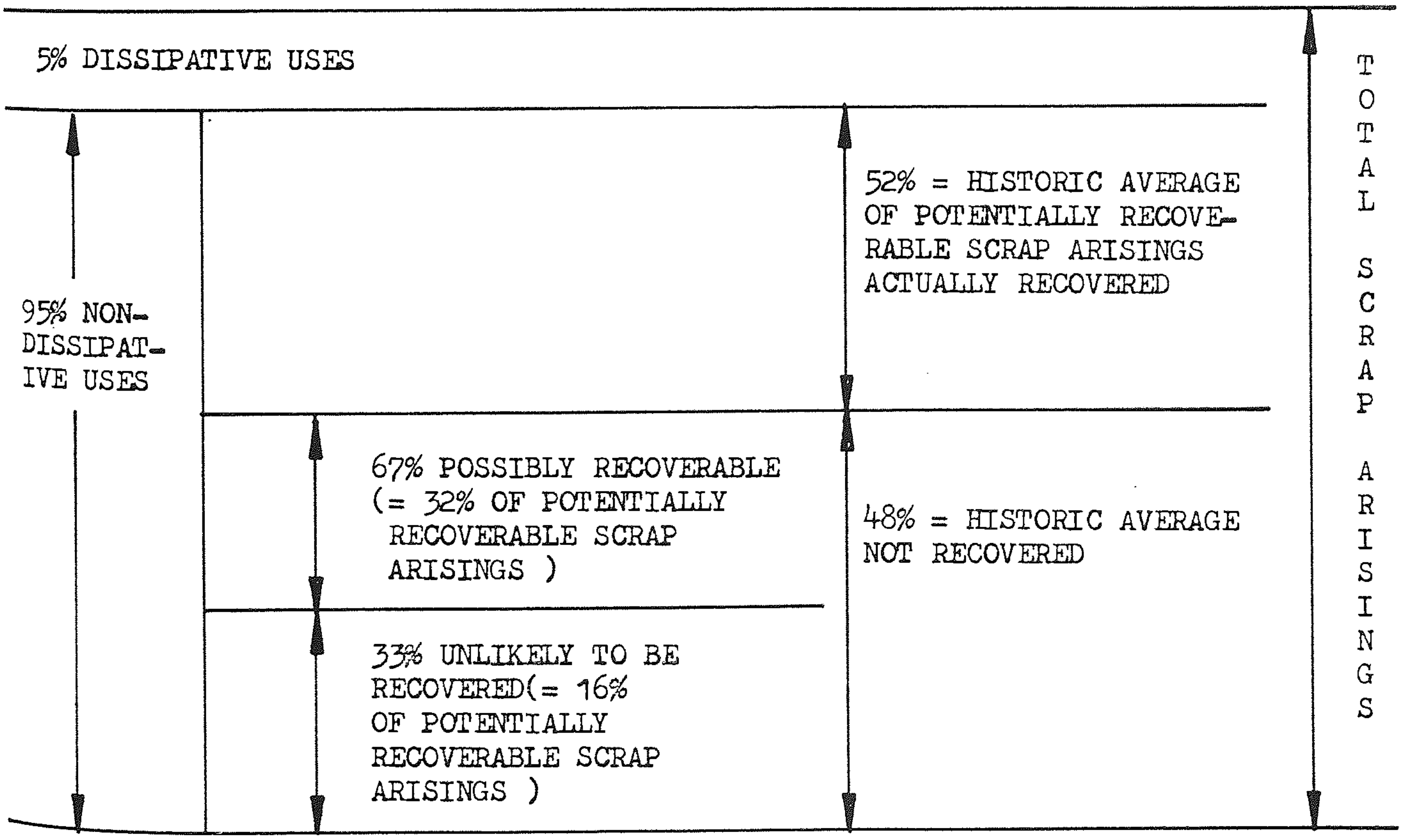


FIGURE 10.6 - BREAKDOWN OF ANNUAL OLD SCRAP ARISINGS

with favourable technological developments. Table 10.7 and Figure 10.5 show the base case forecast of annual potentially recoverable scrap arisings and estimates of likely and possible old scrap recovery. It can be seen that, in 2000, it is likely that 188,000 tonnes of old copper scrap will be recovered, and that an extra 116,000 tonnes of old copper scrap could possibly be recovered, leaving 58,000 tonnes as unlikely to be recovered.

The forecasts of potential old scrap recovery in Table 10.7 will be used in Section 10.4.4 to compare old scrap supply and demand.

10.4 Forecasting Future Total Scrap Demand

In Chapter 9, price dependent and price independent models of copper scrap demand, measured by total scrap collected, were selected. In this section these models will be used to forecast future total scrap demand and, together with the new scrap estimates obtained from the total semis consumption forecasts in Section 10.2, used to forecast old scrap demand. This old scrap demand will then be compared with the forecast of scrap supply developed in Section 10.3 to examine future scrap supply and demand relationships.

10.4.1 Price Dependent Model

The price dependent model selected in Chapter 9 is given below:

$$\boxed{\begin{array}{c}\text{Total scrap}\\ \text{collected, t,}\end{array}} = +38 + 0.4380 \boxed{\begin{array}{c}\text{Total scrap}\\ \text{collected, t-1,}\end{array}} + 0.1668 \boxed{\begin{array}{c}\text{Semis production,}\\ \text{t-1}\end{array}}$$

$$+ 0.1247 \boxed{\begin{array}{c}\text{Real price}\\ \text{of copper, t,}\end{array}} - 0.0929 \boxed{\begin{array}{c}\text{Real price of}\\ \text{copper, t-1,}\end{array}}$$

The following values of the independent variables have been selected:

a) Semis production : semis consumption, modelled in Section 10.2 and semis production are highly correlated. On average, between 1959 and 1976, a nett 10% of semis production was exported and this figure has been used to correct the forecasts of total semis consumption from Section 10.2 to obtain forecasts of semis production.

b) Real price of copper : as developed in Section 10.2.2 the real price of copper has been assumed to grow at a base case rate of 3.5% per annum with high and low rates of 2.4 and 4.4%

The forecasts of total scrap collected using the above assumptions are shown in Table 10.8 and Figure 10.7. For convenience, only the base case forecast of 3.5% growth in real copper prices is listed as the low and high forecasts did not significantly differ (-1%,+2%) from the base case forecasts.

10.4.2 Price Independent Model

The price independent model selected in Chapter 9 is given below:

$$\boxed{\begin{array}{l}\text{Total scrap}\\ \text{collected, t,}\end{array}} = -16.08 + .4179 \boxed{\begin{array}{l}\text{Total scrap}\\ \text{collected, t-1,}\end{array}} + .2528 \boxed{\begin{array}{l}\text{Semis}\\ \text{production}\\ \text{t-1}\end{array}}$$

$$+ .4935 \boxed{\begin{array}{l}\text{Unalloyed semis}\\ \text{production, t-1,}\end{array}} -.4358 \boxed{\begin{array}{l}\text{Unalloyed semis}\\ \text{production, t-1.}\end{array}}$$

The following values of the independent variables have been assumed:

a) Semis production : as in Section 10.4.2, a figure of 10% nett exports of semis production has been assumed to calculate semis production from the forecasts of semis consumption in Section 10.2.

b) Unalloyed semis production : as in the case of total semis production, unalloyed semis consumption and production are highly correlated with a 1959 - 1976 average of 10% nett exports. This figure has been used to calculate unalloyed semis production data from the forecasts of unalloyed semis consumption developed in Section 10.2.6.

The forecasts of total copper scrap collected in the UK using this model are shown in Table 10.8 and Figure 10.7 for the low, base and high semis consumption forecasts selected in Section 10.2.

10.4.3 Forecast Results and the Calculation of Old Scrap Withdrawals

The forecasts of total scrap collected/year shown in Figure 10.7 for the price independent models show a stable trend for the base case of about 300,000 - 325,000 tonnes, a high forecast of 460,000 tonnes by the year 2000 and a low forecast of 208,000 tonnes by the year 2000. The growth rates in Figure 10.7 are not as great as for semis consumption and this will have an effect on old scrap demand. Figure 10.7 also shows forecasts for the year 2000 using the price dependent models using a copper price growth rate of 3.5% per annum. These forecasts fall within a narrower range than the price independent models, but the general agreement beteween the two types of model is good and indicates that the forecasts are not unreasonable.

Table 10.8 also shows estimates of new scrap generation calculated from the low, base and high semis consumption forecasts in Section 10.2 by applying an average fabrication efficiency of 71.4% (See Section 5.4). This assumes that no signfiicant changes in fabrication efficiencies will occur over the period in question - a most unlikely scenario, but as noted in Section 5.4, lack of available data prohibits further investigation in this project, although a general trend towards more sophisticated fabrication techniques (for example, continuous casting and powder metallurgy, is expected to increase fabrication efficiencies.

Old scrap withdrawals may now be calculated by subtracting the new scrap generation forecasts from the forecasts of total scrap collected. Low, base and high forecast results are shown in Table 10.8 and are shown graphically in Figure 10.7.

The price dependent model shows remarkably consistent forecasts of old scrap withdrawals with variations of only -0.8% and +2.4% about the base case. Overall, a slight upward trend may be observed and this agrees well with the base case forecast from the price independent models. Steady upward and downward trends in old scrap withdrawals to 209,000 and 88,000 tonnes/year by 2000 may be observed for the high and low forecasts from the price independent models. The trends in old scrap withdrawals are not as strong as in the case of total scrap collected - this may be explained by the previously noted difference in overall growth rates beetween total semis consumption and total scrap collected.

10.4.4 Comparison of Old Scrap Supply and Demand - 1977-2000

In this section, old scrap demand will be compared with old scrap supply to identify any imbalances. Only likely old scrap recovery (Section 10.3) will be considered here - possible additional old scrap recovery will be considered in Section 10.4.6.

Table 10.9 shows likely old scrap recovery rates (from Section 10.3) and high, base and low scrap demand measured by old scrap withdrawals (calculated in Section 10.4.3). Actual recovery from likely old scrap arisings is expected to decline from 36% in 1977 to 26% in 2000 (Low scrap demand); rise to 38% (base scrap demand) or 58% (in the case of high scrap demand).

FIGURE 10.7 - FORECASTS OF TOTAL, OLD AND NEW SCRAP DEMAND, 1977-2000. (from tables 10.6 and 10.7)

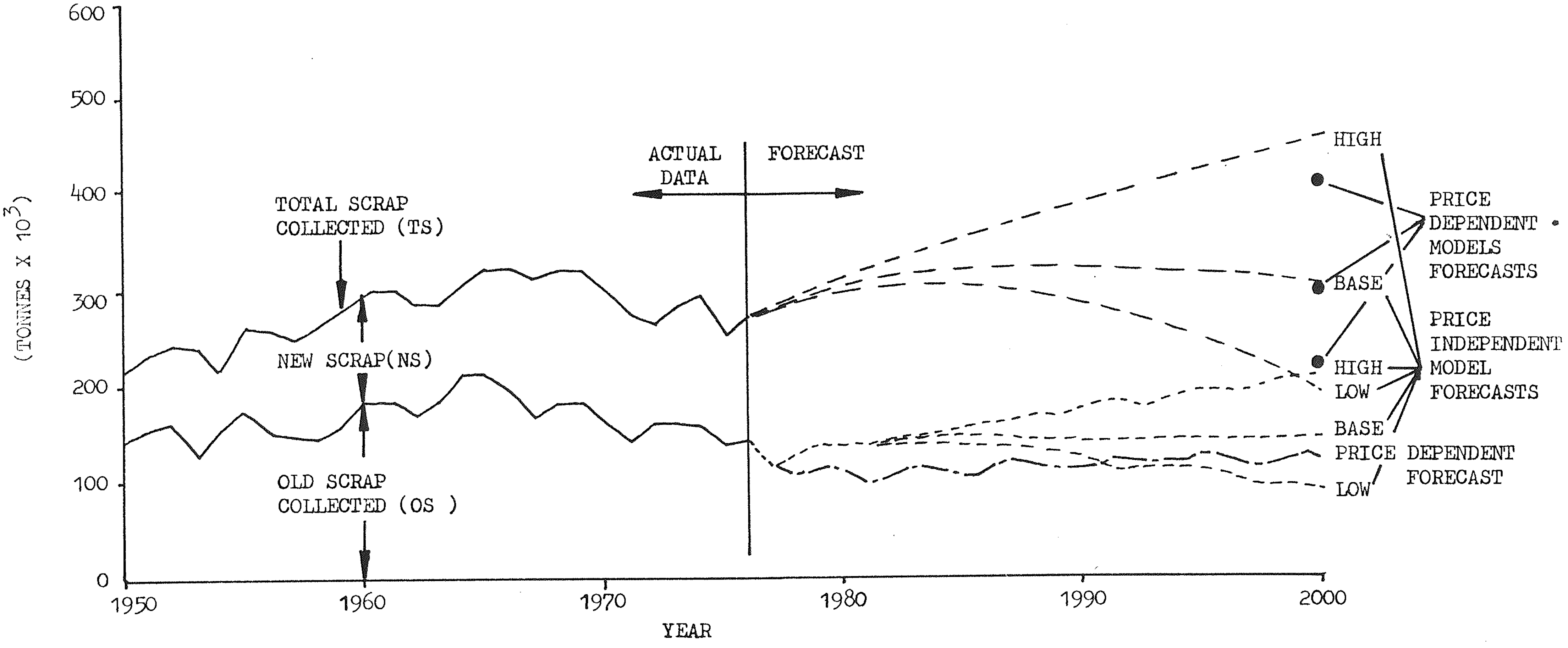


Table 10.8 - Total Scrap Collected, New Scrap Generation and Old Scrap Withdrawal Forecasts,1977-2000, (tonnes x 10^3)

Year	Total scrap collected - price dependent forecast									Total scrap collected - price independent forecast								
	Low Semis Cons Forecast			Base Semis Cons Forecast			High Semis Cons Forecast			Low Semis Cons Forecast			Base Semis Cons Forecast			High Semis Cons Forecast		
	TS	NS	OS	TS	NS	OS	TS	NS	OS	TS	NS	OS	TS	NS	OS	TS	NS	OS
1977	283	170	113	283	171	112	281	167	114	288	170	118	288	171	116	284	167	117
1978	280	174	106	280	175	105	277	172	105	301	174	127	301	175	126	297	172	125
1979	281	169	112	282	171	111	278	170	108	301	169	132	305	171	134	302	170	132
1980	278	172	106	280	175	105	278	176	102	303	172	131	307	175	132	309	176	133
1981	280	180	100	282	184	98	282	188	94	311	180	131	318	184	134	323	188	135
1982	285	178	107	289	184	105	292	191	101	314	178	136	323	184	139	336	191	145
1983	287	170	117	292	177	115	298	188	110	307	170	137	320	177	143	339	188	151
1984	283	170	113	290	178	112	299	193	106	303	170	133	318	178	140	343	193	150
1985	282	176	106	290	186	104	303	203	100	306	176	130	324	186	138	356	203	153
1986	285	173	112	296	185	111	312	206	106	306	173	133	327	185	142	367	206	161
1987	285	163	122	298	177	121	318	202	116	296	163	133	322	177	145	369	202	167
1988	279	162	117	294	179	115	319	207	112	288	162	126	319	179	140	372	207	165
1989	277	167	110	294	186	108	323	217	116	290	167	123	324	186	138	385	217	168
1990	279	164	115	298	184	114	332	220	112	287	164	123	326	184	142	395	220	175
1991	278	153	125	300	177	123	337	217	120	277	153	124	320	177	143	397	217	180
1992	271	152	119	296	178	118	338	221	117	268	152	116	317	178	139	401	221	180
1993	268	156	112	295	185	110	342	232	110	267	156	111	321	185	136	413	232	181
1994	269	151	118	300	183	117	351	234	117	264	151	113	324	183	141	424	234	190
1995	268	140	128	302	175	127	357	231	126	252	140	112	317	175	142	425	231	194
1996	260	138	122	298	176	122	358	236	122	241	138	103	314	176	138	430	236	194
1997	256	141	115	297	183	114	362	246	116	239	141	98	319	183	136	442	246	196
1998	257	136	121	302	182	120	371	249	122	234	136	98	320	182	138	453	249	204
1999	254	124	130	304	174	130	378	246	132	220	124	96	314	170	140	456	246	210
2000	246	120	126	300	175	125	379	251	128	208	120	88	310	175	135	460	251	209

Notes: a) Price dependent forecast at 3.5%/annum growth in real copper price (see text)
b) TS = Total scrap collected
NS = New scrap generation - from semis consumption forecast and assuming 71.4% fabrication efficiency (see text)
OS = Old scrap withdrawals = TS-NS.

Table 10.9 - Comparison of Potential and Actual Old Scrap Recovery 1977 - 2000 (tonnes x 10^3)

Year	Potential old scrap recovery rate (Table 10.7)	Low old scrap recovery			Base old scrap recovery			High old scrap recovery		
		Old scrap recovery (a)	Recovery ratio (b)	Unrecovered old scrap (c)	(a)	(b)	(c)	(a)	(b)	(c)
1977	168	118	.36	50	116	.36	50	117	.36	51
1978	170	127	.39	43	126	.39	44	125	.38	45
1979	158	132	.44	26	134	.44	24	132	.44	26
1980	161	131	.42	30	132	.43	29	133	.43	28
1981	172	131	.40	41	134	.41	38	135	.41	37
1982	178	136	.40	42	139	.41	39	145	.42	33
1983	153	137	.47	16	143	.49	10	151	.52	2
1984	178	133	.39	45	140	.41	38	150	.44	28
1985	190	130	.36	60	138	.38	52	153	.42	37
1986	181	133	.38	48	142	.41	39	161	.46	20
1987	180	133	.38	47	145	.42	35	167	.48	13
1988	183	126	.36	57	140	.40	43	165	.47	18
1989	188	123	.34	65	138	.38	50	168	.46	20
1990	210	123	.31	87	142	.35	68	175	.43	35
1991	206	124	.31	82	143	.36	63	180	.45	26
1992	188	116	.32	72	139	.39	49	180	.50	8
1993	195	111	.30	84	136	.37	59	181	.48	14
1994	217	113	.27	104	141	.34	76	190	.46	27
1995	219	112	.27	107	142	.34	77	194	.50	25
1996	203	103	.27	100	138	.35	65	194	.55	9
1997	185	98	.28	87	136	.38	49	196	.56	-11
1998	189	98	.27	91	138	.38	51	204	.57	-15
1999	192	96	.26	96	140	.38	52	210	.57	-18
2000	188	88	.24	100	135	.38	53	209	.58	-21

a) = old scrap withdrawals, from Table 10.8
b) = actual recovery factor = (a)/annual potentially recoverable scrap arisings (Table 10.7).
c) = (a) - (b) = unrecovered likely recoverable scrap arisings.

Figure 10.8 shows the difference between the quantity of old scrap available using a recoverability factor of 52% (section 10.3) and actual old scrap demand (from Section 10.4.3). In the low and base scrap demand cases an increasing additional quantity of copper scrap could be recovered under suitable market conditions, while the high scrap demand case shows a shortage of available old scrap by 1997.

As explained in Section 10.2 it is anticipated that total semis consumption, and hence old scrap demand, will decrease over the period 1977 to 2000 and so a potential exists to recover up to 100,000 extra tonnes of old copper scrap per annum in 2000, from the likely old scrap section of Figure 10.5. In addition to this volume of copper scrap which is likely to be recovered, a further 116,000 tonnes of possibly recoverable scrap (Table 10.7) also exists. In view of the expected future surplus of old scrap, it is unlikely that this additional scrap will be recovered, but fiscal incentives will also affect this scrap category.

10.4.5 Forecasts of the Pool of Potentially Recoverable Copper Scrap

Using the forecasts of old scrap supply (Table 10.7) and old scrap demand (Table 10.9), significant additions to the 1976 pool of 2.6 million tonnes of copper scrap (developed in Section 8.6) by the year 2000 may be calculated as: low old scrap demand, +5.7 million tonnes; base old scrap demand, +5.3 million tonnes; high old scrap demand, +4.6 million tonnes. If the historic recoverability factor of 52% continues beyond 2000, only the high scrap demand forecast will result in a slow down in the additions to the pool. These figures give a total pool in 2000 of 8.3 million tonnes (low scrap demand) to 7.2 million tonnes (high old scrap demand).

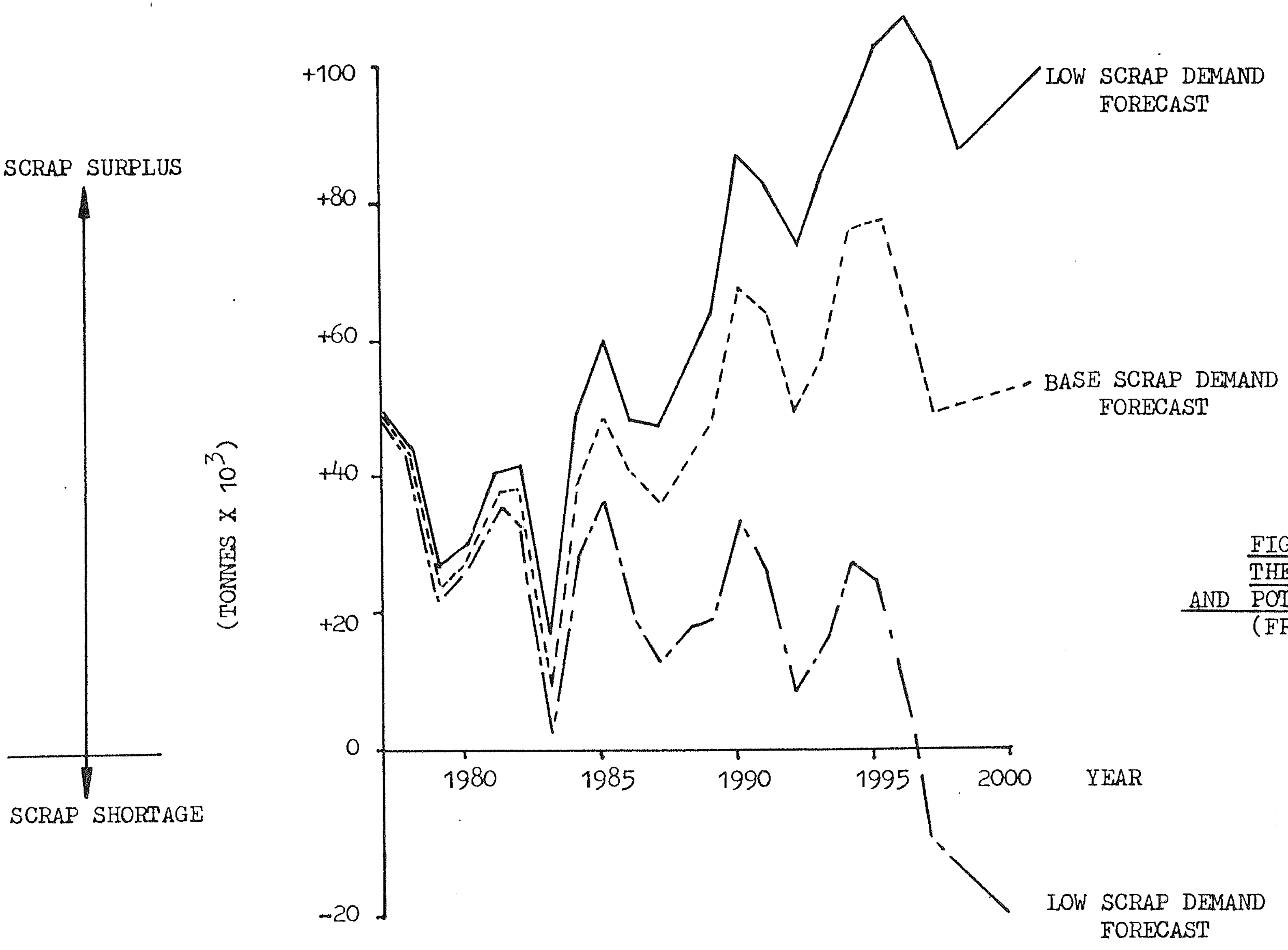


FIGURE 10.8 - GRAPH SHOWING THE DIFFERENCE BETWEEN ACTUAL AND POTENTIAL OLD SCRAP RECOVERY (FROM TABLE 10.9)

It may be argued that this continued growth in the size of the pool of potentially recoverable copper scrap will stimulate increased copper scrap recovery. While this may be true under short-lived conditions (e g.. rapid increases in copper prices or interruptions to primary supplies), the long-term trends identified in previous sections will continue unless selective action is taken to stimulate increased old scrap recovery. Available measures will be discussed in Chapter 11 and recommendations made.

10.4.6 Economic Implications of Increased Copper Scrap Recovery

Having established that a potential exists for increased copper scrap recovery it is necessary to examine the implications and costs of this additional recovery effort.

Table 10.10 shows estimates of future refined copper nett imports, including refined copper produced from imported copper matte and concentrates. This is calculated from the semis consumption forecasts in Section 10.2, allowing 10% for nett international trade in semis (Section 10.4.1) and subtracting the total scrap collected forecasts before allowing for extra recovery effort. Although the quantities involved vary from 258,000 to 514,000 tonnes/y, the contribution of these nett imports to semis production is a remarkably consistent 54-56%, probably reflecting the continued intensive use of imported refined copper in electrical applications.

The effect of increasing old scrap recovery effort to the historical recovery rate of 52%, as described in Section 10.4.4, would reduce nett imports by a similar amount. If, as suggested above, these nett imports are primarily refined copper for electrical uses then any additional old scrap recovery would have to be refined to produce a similar grade material to that it is replacing. Additionally, miniaturi-

Table 10.10 - Nett Imports of Copper Necessary to Satisfy Semis Production, 1977-2000
(tonnes x 10^3)

Year	Low semis consumption forecast		Base semis consumption forecast		High semis consumption forecast	
	Nett imports of copper	% semis production	Nett import of copper	% semis production	Nett import of copper	% semis production
1977	373	56	374	56	363	56
1978	372	55	376	56	370	56
1979	354	54	358	54	358	54
1980	363	55	370	55	373	55
1981	385	55	394	55	404	56
1982	377	55	388	55	404	55
1983	351	53	365	53	388	53
1984	357	54	374	54	403	54
1985	376	55	398	55	431	54
1986	364	54	390	54	432	53
1987	337	53	366	53	415	54
1988	341	54	374	54	429	54
1989	359	55	396	55	458	54
1990	346	55	387	54	458	53
1991	317	53	365	53	442	53
1992	319	54	371	54	456	54
1993	336	56	395	55	486	53
1994	322	55	386	54	484	53
1995	291	54	362	53	470	53
1996	293	55	369	54	484	54
1997	307	56	392	55	514	53
1998	291	55	383	55	514	52
1999	260	54	359	53	499	52
2000	258	55	366	54	514	53

sation and economies of use will produce more lower grade scrap which cannot be used directly and instead will have to be refined. Both the above developments indicate that the recent downward trend in secondary refining will have to be reversed.

The potential Balance of Payments savings are considerable: at an assumed copper price of £1,000/tonne of a Balance of Payments saving in the year 2000 of £100 million/y may exist for the low semis consumption forecast; £53 million/y for the base case forecast; while additional refined copper imports valued at £21 million/y may be necessary for the high forecast. An alternative for the latter case and a possibility for the other cases is to recover some of the possibly recoverable copper scrap identified in Table 10.7 (116,000 tonnes in 2000). This may be possible, but fiscal or regulatory incentives are believed necessary to increase the historical recoverability factor.

In Chapter 4, a total UK secondary refining capacity of 280,000 tonnes per annum was identified but a significant downturn in UK secondary refined copper production since 1970 (Figure 5.9) indicates that one or more of these plants are either being closed or run-down. In fact, the only significant change in Table 4.10 is that the British Copper Refiners plant at Widnes closed in 1975 with a loss of 130,000 tonnes capacity or 46% of total secondary refining capacity. The closure was blamed on insufficient profit, but the continuing existence of the other refineries indicates that the extra volumes of old scrap for refining resulting from the closure may be a significant component in reducing their unit operating costs. This is supported by the fact that in 1976, 137,000 tonnes of UK refining capacity was utilised, although only 86,000 tonnes of secondary refined copper was produced, the balance being primary refined production from imports of matte and concentrate.

The changing pattern of scrap arisings and quality makes forecasts of the direct use of scrap and the production of secondary refined copper (from the models in Chapter 9) of limited use as the blend between these two flows necessary to satisfy the semi-manufactures will have altered. For this reason and concern over the model structure the rest of this work will concentrate on the total scrap collected and the investment necessary for the plant to refine the extra volume of unrecovered old scrap identified above.

The investment requirements put forward are not estimates of what actual investment will be, rather they are statements about what investment needs to be, if the extra volume of old scrap identified earlier is to be usefully employed.

Lack of available data on secondary copper investment costs meant that only a single report was found. This report, of unknown date but assumed to be 1978, prepared by the Commodities Research Unit (CRU) (in (93)), considered that the capital costs of a smelter and refinery for low grade secondary materials would be very similar to those for constructing new primary capacity and were estimated as being:

	US \$ per ton of output
Reverberatory furnace and converter	400
Electrolytic refiner	400
Reverberatory furnace and casting plant for shapes	100
Electric melting and casting facilities	300
	1200

This corresponds to a 1978 capital cost of £670/tonne or a total investment by 2000 of £67 million to refine the 100,000 tonnes/y of likely recoverable copper scrap identified in Section 10.4.4. Although more work is required on assessing investment costs for secondary refining plant, the above analysis provides rough estimates and indicates that a real £33 m investment would be necessary even to recover the additional 53,000 tonnes of copper scrap for the base case scrap demand forecast. Lack of accurate and complete processing costs for secondary refined copper means that determination of payback times is difficult. However, a payback period of five years would require processing costs to be £150/tonne below the price received for refined copper. A more detailed project analysis based on Return on Investment is necessary to provide conclusive evidence for the profitability of a secondary refining plant and to determine whether existing plants are completely depreciated, so minimising costs. Additionally, the effect of by-products on profitability must not be forgotten; one medium sized British secondary refiner (93) regarded its sales of precious metals, tin-lead alloy and nickel from tank-house slimes to be essential to its commercial viability.

United Kingdom secondary refining capacity should expand at 4% per annum until 2000 to achieve the objectives outlined above. While this expansion may be achieved by additions to existing refining capacity, an alternative is to build a single new refinery capable of handling the total 100,000 tonnes/y, at a site near to a large source of scrap. Figure 4.6 shows that existing refineries are located in the North West and Midlands; no refinery is located at London, although significant semi-manufacturing capacity is located in this area.

It is therefore proposed that a single new refinery be built in the middle 1980's in the London area, with a capacity of up to 100,000 tonnes/y (any temporary spare capacity, as with existing refineries, to be used for primary copper refining) at a cost of about £67 million in 1978 prices. An examination of the effects of this new refinery upon scrap supplies to existing refineries should be carried out, but is beyond the scope of this project.

While it is true that investment in a new refinery would create employment, make the UK more self-reliant with respect to copper supplies and improve the Balance of Payments by between £100 m to £55 m, certain penalties must be paid. These are principally increased UK energy usage and pollution levels.

In Chapter 2, it was noted that the energy costs of producing copper are a quarter of those to produce primary copper. However, with imported primary refined copper the energy cost of 120 GJ/tonne (148) is external to the UK; with UK secondary refining operations handling the additional 100,000 tonnes/y of old scrap the energy costs of 30 GJ/tonne, or £48/tonne at an 1978 energy cost of £1.6/GJ (148), is internal to the UK and would result in a total energy bill of £4.8 million/y in 1978 prices or 280,000 barrels of North Sea Oil/y equivalent. This estimate of energy use is initially incompatible with a CRU estimate (93) of total processing costs for low grade scrap of at least £180/tonne at an unknown date, but assumed to be 1978 - the year before publication - of which 50%, or £90/tonne, are energy costs. Close examination of copper scrap prices in Metal Bulletin (171) and prices offered by scrap merchants (172) reveals that the processing costs given above are for the extremes of copper content in scrap acceptable to the secondary refiners, i.e. 10-40% copper (Figure 4.3). At a 1978 LME refined copper price of £875/tonne (171) the cost of a 12% and 35% copper content scrap would be £320 to £400/tonne of copper content respectively - a range of approximately £100/tonne. This compares well with the range in processing costs given earlier (£90-£180/tonne), indicating that these processing costs are compatible - but only if the copper content of the scrap is taken into account. These processing costs will be used later in a breakdown of secondary refining costs.

Pollution control costs are difficult to determine as they are dependent upon the type of scrap being processed and current and proposed pollution legislation. In the USA, over half the emissions of cadmium to the atmosphere comes from metal wastes (Pearce (57)) while another US report (38) estimated that £60/tonne (1977 prices) would be needed to be added to investment costs for the more stable primary copper pollutants (Table 4.2) in view of tightening environmental legislation. No other empirical work, specific or otherwise, to the UK has been found, but such work, which is beyond the scope of this project, is needed to present as complete a picture of current and future operating costs as possible.

Using the above analysis, it is now possible to estimate a breakdown of 1978 UK secondary refining costs as shown in Table 10.11.

Table 10.11 - Breakdown of Secondary Refining Costs, 1978 Prices

£/tonne of copper content

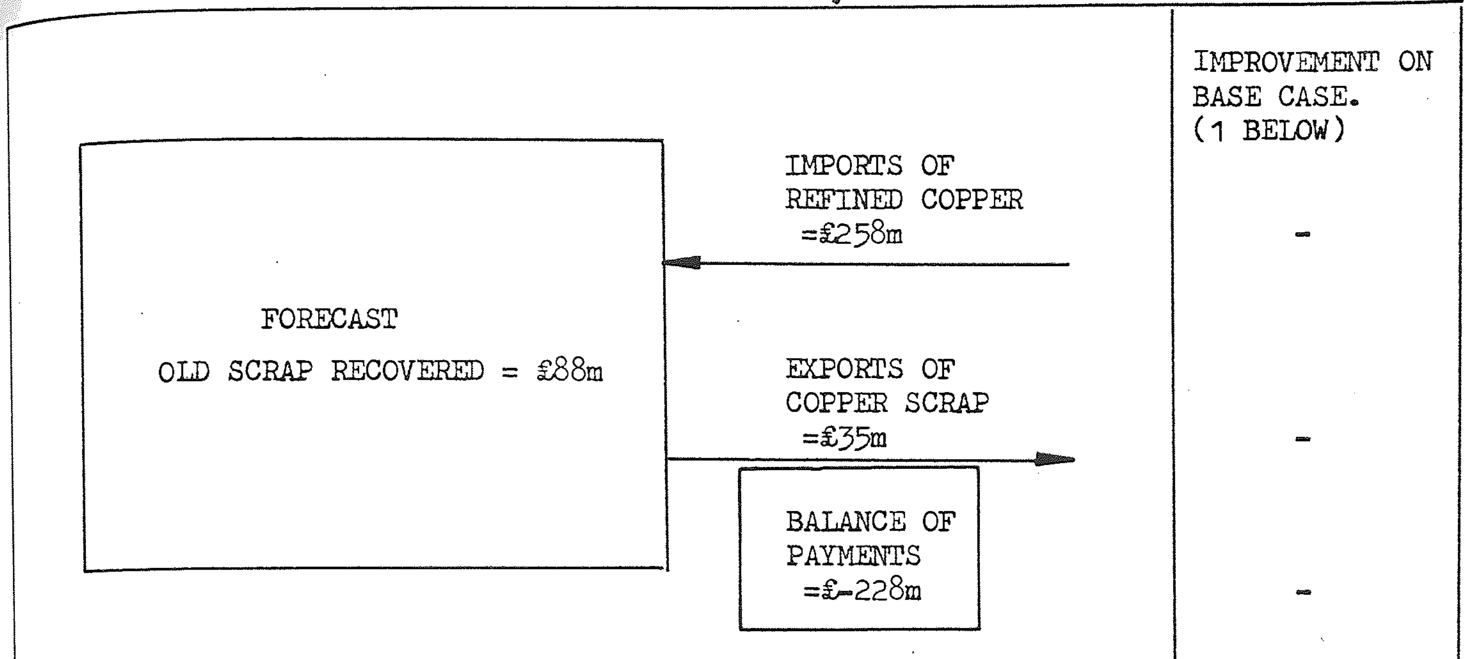
Processing costs = 180
(of which Energy costs = 90)
Raw material costs = 320
Total operating costs = 500

Selling price = 875
Therefore "profit" = 375

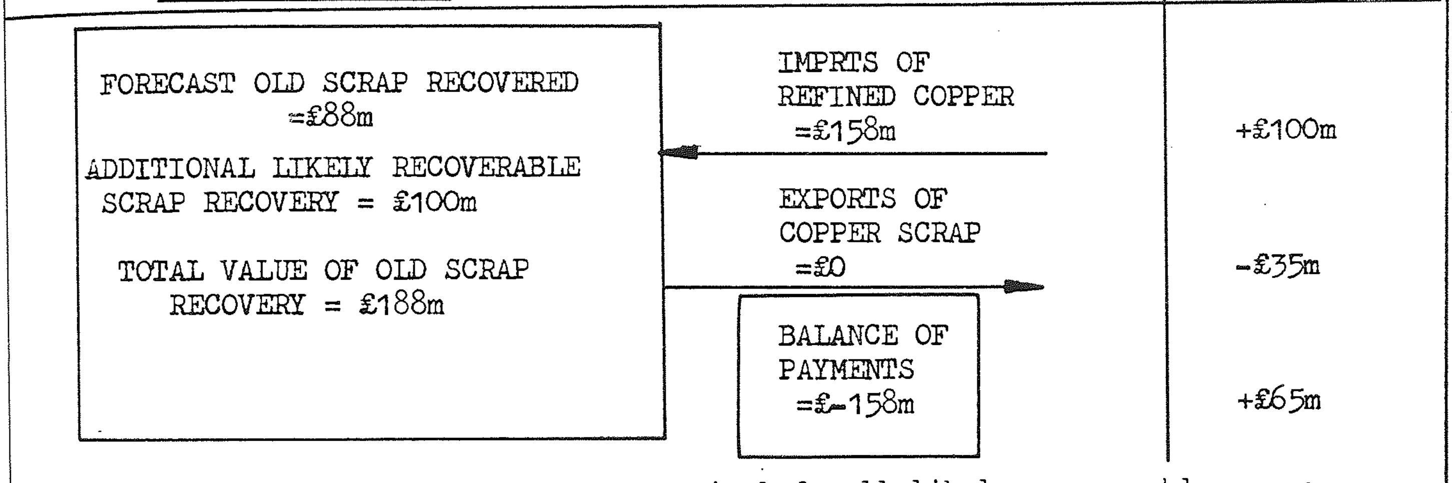
This crude analysis reveals that in 1978, a 12% copper scrap would yield a profit equal to 43% of the LME refined copper price, although this does not take into account any capital repayments on the plant employed. This means that even if, as is commonly thought (157), (84), existing UK secondary refining plant is fully depreciated, the potential for capital repayments for the new secondary refinery proposed earlier exists.

An overall economic balance for the year 2000 covering the forecast status quo situation and increased likely and possible copper scrap recovery situations is given in Figure 10.9. As explained earlier, the forecasts of old scrap recovery in 2000 will result in imports of £258 m of refined copper at 1978 prices. If additional recovery effort is not instigated, it is likely that the recent trend towards exporting copper in scrap to other EEC countries (principally West Germany and Spain (165)) will continue. This will result in exports of 100,000 tonnes of copper in scrap valued at £35 million pounds (using the analysis of scrap prices presented earlier). While these exports do contribute to a Balance of Payments saving, they do not contribute to the stability and security of the UK copper industry and so are undesirable.

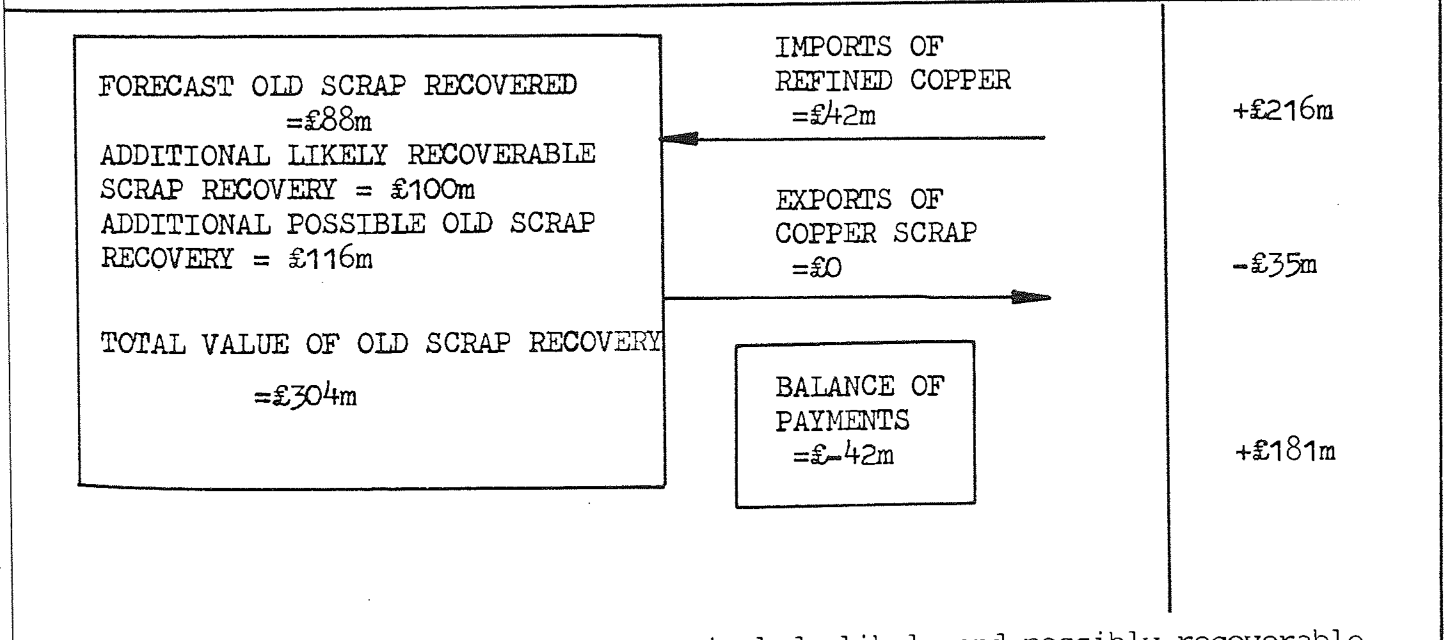
If all the likely recoverable scrap (100,000 tonnes/y - Section 10.4.4) is recovered, imports of refined copper and copper in scrap would drop by £100 million and £35 million respectively and an overall Balance of Payments improvement of £65 million would result. This significant Balance of Payments saving could finance the necessary investment in secondary refining plant of £67 million either in a single year or spread over five years. Of course, these figures are maxima and immediate benefits of the size described would not result until the year 2000. A more complete financial analysis over the entire period is necessary to identify the exact timing necessary to maximise import and operational savings, but such work is not possible in the time available for this project.



1) No increased scrap recovery to 2000 beyond demand forecast in section 10.4.5.



2) Increased old scrap recovery to include all likely recoverable scrap



3) Increased old scrap recovery to include likely and possibly recoverable scrap.

NOTE: m = MILLION

Figure 10.9 - Economic Implications of Increased Old Scrap Recovery in the year 2000 (1978 prices)

Finally, Figure 10.9 shows the economic effect, in the year 2000, of the recovery of both the likely (100,000 tonnes/y) and possible old scrap (116,000 tonnes/y) identified in Section 10.4.4. Additional import savings of £116 m would arise, giving a total Balance of Payments saving of £181 m for a capital investment of £145 m. Taking the situation one step further, in Section 8.6 a 1976 pool of potentially recoverable scrap of 2.6 million tonnes was identified. Assuming that 40% of this pool is possibly recoverable (Section 10.4.4), the potential for the UK to be self-reliant for refined copper supplies in the year 2000 exists if an additional 42,000 tonnes/y of copper in scrap is recovered from this pool. This ideal situation would provide significant economic and social benefits for the UK in the form of, for example, employment, Balance of Payments savings and contribution to GNP but firstly, the reasons why this and the likely recoverable scrap are not currently recovered needs to be examined and recommendations made. As explained in Section 8.8, this is not possible with existing data and more work, beyond the scope of this project, is necessary before accurate recommendations can be made.

How long this self-sufficiency can last is difficult to determine. Although reasonably accurate forecasts of potentially recoverable scrap can be made up to say, 2030, forecasts of old scrap demand are more difficult to determine. Various scenarios are shown in rough form in Figure 10.10. The high growth in old scrap demand shown would arise, for example, if semis production grew from 2000 or new technology was developed for old scrap recovery. The medium and low scenarios assume either a continuation of the trends identified in this Chapter beyond the year 2000 or a decline in old scrap demand, possibly due to a fall in semis production or a technologically insurmountable decline in old scrap quality. The scenarios are very difficult to accurately determine and are certainly beyond the scope of this project, although qualitative models may provide some indication of future trends.

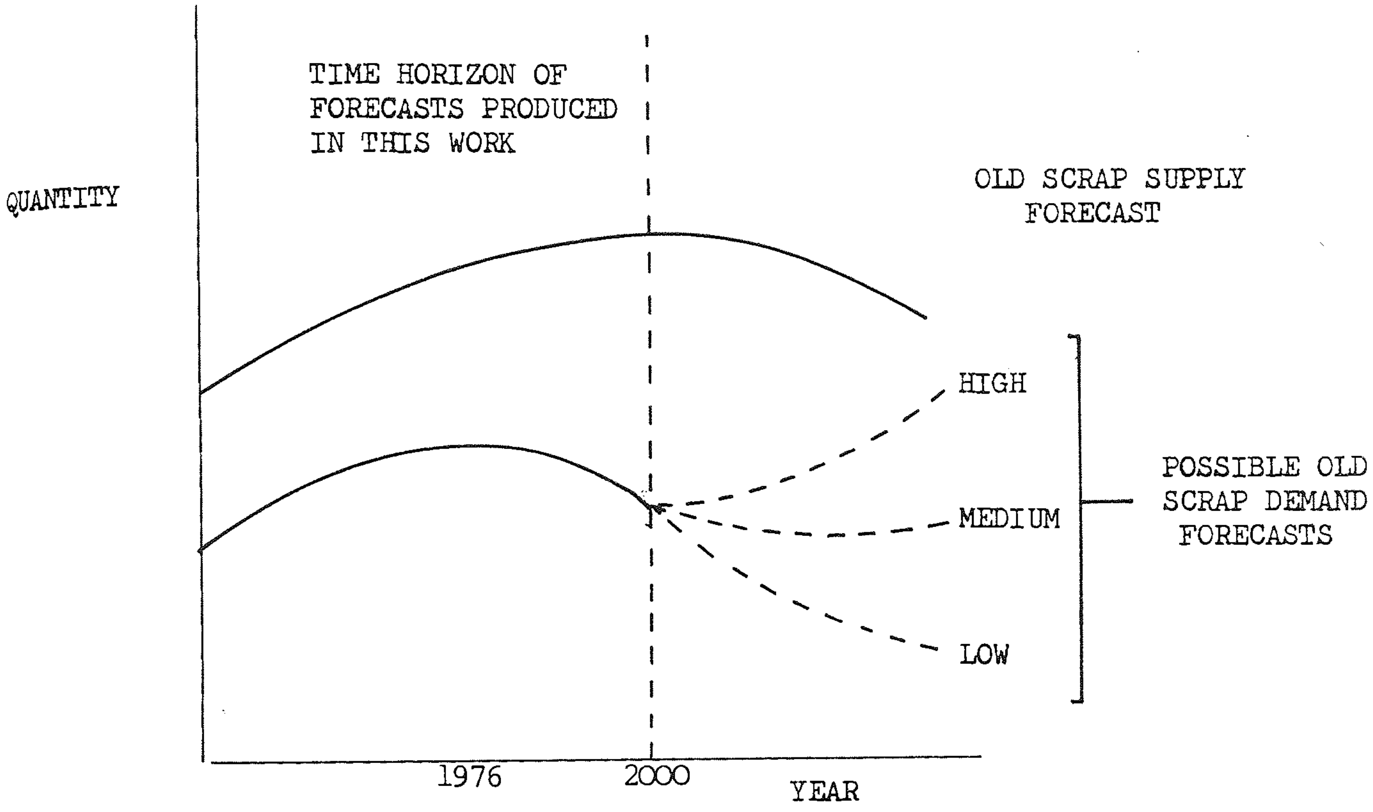


Figure 10.10 - Alternative Scrap Supply and Demand Scenarios Beyond the Year 2000

Summarising, potential for increased old copper scrap recovery exists to four different levels. Firstly, recovery to the levels forecast for the year 2000 in Section 10.4.3 would result in a Balance of Payments deficit of £223 m (at 1978 prices). Secondly, investment of £67 m over five years in secondary refining plant to recover up to 100,000 tonnes of likely recoverable copper in old scrap would reduce the annual Balance of Payments deficit by £65 m. Thirdly, recovery of up to 116,000 tonnes of possibly recoverable copper in old scrap would further reduce the Balance of Payments by £116 m at an additional investment cost of £77 m over five years. Finally, the UK could be made self-sufficient in refined copper supplies by 2000 by the additional recovery of 42,000 tonnes of copper from the growing pool of potentially recoverable scrap identified in Section 8.6.

10.5 Summary to Chapter 10

Using the models developed in Chapter 9, forecasts of total, unalloyed and alloyed semis consumption, total scrap collected and scrap supply have been made under various growth scenarios.

The forecasts of total and unalloyed semis consumption made using the industrial production dependent models developed in Chapter 9 resulted in higher growth rates than the industrial production independent models. The latter models produced growth rates compatible with historical trends and a break between industrial production and demand has been identified. Low, base and high forecasts were selected. A trend toward miniaturisation and economies of use was identified and a slow substitution of newer materials (such as optical fibres) for copper is expected to continue. Overall, copper semis consumption is expected to decline or remain stable and contrasts sharply with other, industrial production dependent, models developed by other workers.

UK copper scrap supplies will continue to grow as the high copper goods consumption of the 1950's and 1960's become available. The forecasts were insensitive to the low, base and high semis consumption forecasts. A corresponding increase in the potential for increased old scrap recovery is expected. The effects of miniaturisation and economies of use on the recoverability of this scrap is unclear, but technological developments are expected to balance any deterioration in scrap quality. Three types of copper scrap arisings were identified - firstly copper scrap that has historically been recovered; secondly, a volume of scrap which is possibly recoverable, but which historically has not been recovered and thirdly, a volume of scrap which, while potentially recoverable, is not likely to be recovered.

The price dependent and independent models of total scrap collected produced similar forecasts for the low, base and high semis consumption scenarios. Although fabrication efficiencies are expected to rise, lack of available data meant that a historical average figure was used to calculate new scrap generation and so old scrap withdrawals.

Comparison with the forecasts of likely scrap supply showed that the potential exists to recover an extra 50,000 to 100,000 tonnes of copper scrap in the year 2000, for the low and base scrap demand forecasts.

Nett imports of refined copper are expected to average 54-56% of copper semis production over the period 1977-2000 and it is suggested that electrical uses will consume this volume of refined copper. If this is the case, the unrecovered potentially recoverable copper scrap will have to replace some of this copper if a market for this material is to be found. As the higher grade copper scrap will be recovered first and be sorted to be used in the traditional uses i.e. directly by the semi-manufactures, any extra copper scrap recovery would have to be in the form of secondary refined copper.

The economic implications of any increased old scrap recovery were examined. This covered the capital and operating costs involved and the effect on the UK Balance of Payments. Lack of data on capital and operating costs limited discussion to a general level, although significant differences between operating costs were accounted for by varying scrap grades. Large Balance of Payments savings are possible due to increased old scrap recovery above the levels forecast by the models described earlier. Increased old scrap recovery to a level including all the likely and possibly potentially recoverable old scrap arisings and a small proportion of the 2000 pool of copper scrap would result in the UK being self sufficient in refined copper supplies.

The necessary investment in secondary refining capacity to recover the more readily available 100,000 tonnes of copper in scrap identified earlier would be up to £67 million. Besides benefiting the UK Balance of Payments, such investment would provide employment and a stable source of copper supplies. The alternative is to allow the export of copper scrap to continue to rise - an alternative which has little practical benefit to the UK other than a short-term financial gain.

The significant national, economic and social benefits arising from increased old scrap recovery led to the conclusion that the exploitation of this potential is too important to be left to the UK copper industry alone. Instead, it was concluded, government actions designed to provide the necessary incentives for the UK copper industry to invest in secondary refining capacity are necessary. Possible options will be examined in Chapter 11 and recommendations made.

CHAPTER 11 - RECYCLING POLICY - A U.K. PERSPECTIVE

11.1 Introduction

Chapter 10 concluded that there was a growing potential for increased recycling of low grade copper scrap in the UK, possibly even to for self sufficiency and that economically and socially this increased recycling would benefit the UK. This Chapter explores the policies needed to fulfill this potential, their cost and applicability to the UK.

Governments of developed countries have historically followed a policy of non-intervention in the recycling industries, but recent concern over material supplies (Chapter 2) has prompted interest in such policies. As yet, the UK government has not developed the types of policies required to achieve significant changes to existing recovery practices. The last few years have seen a great many general research and policy documents relating to resource management, but little positive legislation has occurred. This is probably because action to promote recycling is only one part of a more general government programme designed to encourage the rational use of resources, to reduce waste, to reduce import dependence and to minimise pollution. Only if government perceives recycling as an important step in achieving these broader goals are they likely to adopt the necessary policy measures. The policy measures discussed in this chapter, while specific to scrap copper, are designed to contribute to the governments overall resource management programme. Finally, it must be remembered that increased scrap copper usage in the UK will have a back-linkage effect on production, and hence employment, in developing countries.

11.2 Existing UK Policies and Policies in Other Countries

No significant government policies covering the collection of scrap metal and its processing in the UK have been identified. No direct financial incentives as yet have been offered, although they have been discussed for many years. After the publication of War on Waste (166) the Waste Management Advisory Council (WMAC) was set up in 1974 to keep under review the development of waste management policies, to give particular consideration to resource recovery, the technical, economic, administration and legal problems involved and to consider the program of research and development (167).

Over recent years the emphasis has been on those sectors over which the government has at least some control. In particular, increased recovery effort for paper, glass and other materials contained in the domestic refuse stream has been encouraged by sponsoring sorting plants, R and D (170), advertising and a substantial grant for capital investment in waste paper recovery plants. The fact that a great deal of debate and disagreement over the decision to provide this limited help to a sector where large potential savings have been identified (58) does not bode well for the scrap copper industry. Although not stated definitively in any published report, the general impression is that the UK scrap metal, and in particular scrap copper, industry is considered to be effective in recovering and recycling a large proportion of available scrap arisings. The government considers that other sectors can provide greater savings, despite the fact that exports of low grade copper scrap to countries inside the EEC are increasing. How rising energy prices or potential future interruptions to virgin supplies will affect this view is uncertain, but policy decisions need to be made in good time to prevent an unnecessarily expensive lead time to their implementation.

At EEC level general recycling policy has been debated at a high level for many years, with several working parties for example, covering the basic groundwork on identifying and assessing inventories of secondary materials. This work is continuing and no formal policies have been proposed (93).

In France, a national agency has been set up to organise copper scrap collection from French local authorities and factories. Eventually, at least four secondary copper refineries, each of around 20,000 tonnes/annum capacity will be built so as to reduce, if not end, imports of copper scrap into France. Fiscal incentives to collect scrap also exist. For example, grants are available for between 20 and 50% of the costs of installing plants to treat household waste. The Bureau International de la Récupération (an industry/government liaison body) is currently pressurising for a scheme to reduce freight charges for scrap from outlying areas to refineries - an unlikely scenario for the UK although the siting of new UK refineries should take this factor into account (93). A secondary metal exchange, performing a buying and selling function is also proposed.

The four Scandinavian countries belong to the Nordic Wastes Market where prices of internally collected and recycled waste materials are government controlled. Few fiscal incentives on the collection and recycling of base metals exist.

In the US, government policies and legislation affecting copper base scrap have centred upon freight rates and tax benefits. Freight rates have already been mentioned as significant in some cases above. Generally no tax allowances for copper scrap exist and this contrasts strongly to the depletion allowances which exist for US primary production (93).

Generally, a great deal of administrative and committee work has been poured into identifying, measuring and examining the effects of various resource management policies. As these policies are usually part of an overall resource management programme and few significant practical schemes are in existence on which to base expected results, no major policy schemes have been implemented. As is the case for policy decisions in other areas, many governments are queuing to be second. Hopefully the UK government, in co-operation with the UK copper industry, will be prepared to implement the scheme(s) to be developed in this chapter, which will achieve the objectives of recovering the available copper scrap identified in Chapter 10. Unfortunately, history indicates that it is more likely that the market dislocation such policies will produce will have a disruptive effect on other industry sectors and, instead, the government will (eventually) introduce an overall resource management policy instead.

11.3 Selection of Copper Scrap Recovery Policy Measures for the U.K.

In order to bring about the necessary action to promote copper scrap recycling, the government has a choice between intervention of some type (through regulations or fiscal incentives) and encouraging voluntary action. Generally, the UK has followed the latter route. In some cases, an incentive for action may be the knowledge that the government is actively considering intervention. For example, the extent to which the Bottle Bank Scheme introduced by the Glass Manufacturers Federation was influenced by a possible ban on returnable bottles is unknown. While these incentive schemes are commendable, a more positive regulatory policy is felt to be necessary for the UK to utilise the increased volume of low grade copper scrap becoming available to the end of the century.

In discussing possible policy measures a distinction must be made between actions to increase the demand for secondary copper and actions to increase supply. Some measures, such as the Waste Material Exchange in the UK, will promote both. Taking action solely to encourage copper scrap supply is likely to depress prices and may result in some of the scrap supply finding no market at all. This has historically been true for the waste paper market where wide fluctuations in price have been blamed on excessive voluntary supplies. Actions to promote demand may result in short-term shortages and temporary high prices, but such measures are likely to provide incentives for scrap merchants to increase supply. The converse (i.e. that increased supply will lead to increased demand) may not always be true.

In Chapter 10 it was shown that a surplus of scrap supply over demand of up to 100,000 tonnes of copper/year will occur to the end of the century. The rest of this chapter will concentrate on identifying policies which will promote the demand, and not supply, for copper scrap. AVailable policy tools identified in Chapter 2 are:

1) A disposal tax
2) A virgin materials levy
3) A general pollution tax
4) A virgin materials tax
5) Direct subsidies to scrap copper reclaimers
6) Incentives to scrap copper users.

1) A disposal tax, designed to correct the divergence between private and social costs of a product containing copper would increase the supply of copper scrap to a value over and above that calculated in Chapter 10. Such an increase in supply has already been determined

to be undesirable unless a corresponding increase in demand exists. Generally, real disposal costs are rising, making recycling a more attractive proposition. The trend towards miniaturisation and economies of use of copper in goods indicates that unless action is taken to promote the design of these goods for recycling, increased recovery effort will not be possible and an increasing volume of potentially valuable discards will have to be disposed of. A disposal tax is a possible means to ensure that for example, all the major copper components of a car are located in an area where they can be easily recovered, for example, alongside the radiator.

The magnitude of a disposal tax is a complex problem and detailed work is necessary before suitably accurate recommendations can be made, but generally the charge should equal the costs of managing the solid wastes associated with the copper bearing goods (168). If the disposal tax is calculated by weight, there would be a move towards lighter goods, further reducing the copper content of the scrap. If calculated by value, with exemptions for the scrap copper content, a gradual but unknown shift to less expensive materials will occur with a resultant drop in revenue. This revenue could be reallocated to cover local authority disposal costs or instead could be used to finance the £67 million necessary for additional secondary refining plant identified in Chapter 10. UK consumption of copper in goods in 1976 was 355,000 tonnes and a disposal charge of £38 per tonne (or 5% of refined copper prices) would be required to raise this capital over five years. While not a significant proportion of copper prices, a disposal charge would increase imports of cheaper fabricated goods and adversely affect UK export markets.

Summarising, disposal taxes are difficult to determine accurately and, if only applied in the UK, would adversely affect imports and exports of fabricated goods. The alternative virgin materials tax may be specifically applied to refined copper imports and is preferred to the disposal tax described above.

2) The UK is likely to be on the receiving end of a virgin materials levy on copper designed to restrict virgin consumption and conserve valuable finite copper reserves located, generally, in developing countries. Historically, CIDEC, the copper producers association, who would probably agree and administer a virgin materials levy, have been unable to develop policies in more significant areas, such as primary copper price stabilisation. Agreement on a virgin materials levy is unlikely. While such a levy would make copper scrap more competitive the lack of control exercised by the UK government over such a levy makes it unattractive compared to the virgin materials tax on copper imports to be discussed later. Additionally, as most of the refined copper supplied to the UK is based on the LME free market price (Chapter 6) any such levy would probably drive customers to the US producers, unless they too were party to such a levy. The close relationship described in Chapter 6 between primary and scrap copper prices would lead to similar movements in scrap copper prices and further economies of use and substitution would occur rather than the objective of promoting demand for copper scrap.

The lack of UK control over a virgin materials tax leads to its exclusion as a potential UK regulating mechanism, although many of the advantages and disadvantages such a levy may be applied to the virgin materials tax described later.

3) A General UK Pollution Tax, as explained in Chapter 2 for the general case, would have a detrimental effect on the demand for copper scrap in the UK. Capital and operating costs for copper scrap recovery would be

higher in the UK than for the untaxed foreign primary producers unless a global pollution tax were introduced. As this would require intergovernmental negotiations between primary suppliers and consuming countries, it is unlilely that such a tax will be introduced within the lead time necessary to exploit the unrecovered potentially available copper scrap identified in Chapter 10. The environmental effects of recycling copper may be significant: for example, over half the emissions of cadmium to the atmosphere each year in the US comes from the disposal of metal waste, principally from scrap steel and copper from radiators (Pearce (57)). Rather than allocating this cost to the copper scrap recovery operators, goods should be designed to avoid this problem. This would require regulatory or fiscal incentives, such as the virgin materials tax described in the next section.

A General Pollution Tax, if applied, may be based upon the extent and nature of the pollutants produced and would need to be applied throughout the copper and other process industries on a consistent basis. It is not possible in this work to estimate the size and scope of such a tax, but the above analysis indicates that a general pollution tax would not be a suitable incentive for increasing copper scrap demand, particularly if such a tax was interpreted as a "license to pollute".

4) <u>A Virgin Materials Tax</u> on copper imports to the UK would have to cover both virgin and secondary copper as the aim is to reduce the import dependence of the UK. By artificially raising the UK price of primary copper to a level reflecting the national economic cost of its use in preference to recycled materials, copper scrap recycling would be stimulated. The revenue generated could be used to finance the secondary copper refinery plant proposed in Chapter 10. With nett UK refined copper imports of 355,000 tonnes in 1976, a virgin materials tax of

£38/tonne over five years would be necessary. The similarity of this figure and the disposal tax proposed earlier is due to the fact that UK nett imports of refined copper and the consumption of copper in goods were equal in 1976. Therefore, a tax could be applied at either the raw material or finished good stage of the UK copper industry to finance the proposed secondary refinery. Although a disposal tax would probably be preferred for an overall resource management programme because of its general application potential and direct link with rising disposal costs, a virgin material tax on imported refined copper would provide direct incentives to secondary copper users and processors to increase their throughput of copper in scrap. Such a tax would be difficult to quantify and implement, but its potential as the most direct capital raising mechanism available merits its recommendation as a UK policy tool. The backward linkage effect of such a tax on developing countries would be more direct than other measures designed to promote copper scrap reycling. The more indirect subsidies to scrap copper users may be preferable e.g. by establishment of a buffer stock scheme or a guaranteed floor price or specifying a minimum copper content.

5) Direct subsidies to scrap copper reclaimers and recyclers to stimulate copper scrap demand could be in the form of grants, price support systems (see incentives to reclaimed copper users) and accelerated depreciation allowances on equipment and buildings used for reclamation and recycling. The maximum level of such subsidies would be set by the import savings and social costs (e.g. employment, pollution) involved.

In Chapter 10 it was identified that approximately £33 million to £67 million investment in new secondary refining plant is necessary.

While it is possible that the UK copper industry could finance such investment by themselves, they would probably be looking to the government for some of the capital involved. The analysis of virgin material taxes presented earlier indicates that a tax of £38/tonne over five years would finance the necessary investment. The governments problem lies in the fact that it would wish to promote the recycling of the unrecovered copper scrap and not the currently recovered scrap. Investment in secondary refining capacity could be part of an overall modernisation of the UK copper secondary refining industry and the contribution of new scrap, old scrap and, in particular, currently unrecovered scrap to secondary refined production would be difficult to measure. Certainly, investment of this nature to increase the demand for scrap copper could not be undertaken without the parallel consideration of incentives to scrap users to be discussed later. This would involve the development of more complete UK copper scrap flow statistics than exist at present. A disincentive for copper scrap exports should be investigated although this would have to be an EEc developed policy.

In Chapter 4 it was shown that copper is a major, but not the only, metal dealt in by scrap merchants and close control of any grants towards copper recovery equipment should be exercised to ensure that metals not as important to the UK as copper are not recovered using this equipment. Overall, the more complex equipment needed in the future to handle and segregate copper scrap is likely to reduce the number of scrap merchants involved in scrap copper.

Direct subsidies to copper recyclers may also take the form of research and development into new technologies either at government funded institutions or at private industrial organisations. In particular, the necessary new technology for less costly and more efficient recovery practices should be investigated to ensure the upgrading of copper from future low grade sources. The ability of copper or any other metal scrap to be refined back to a virgin specification implies that work on developing alternative, down-grading, uses for copper should be discouraged.

All the above measures would increase the supply, as well as demand, for scrap copper and while the primary aim of this chapter is to identify means to increase demand for copper scrap, the policies and work described above is necessary to ensure an adequate flow of recycled copper once a demand has been established. This supply would be best promoted by direct incentives in the form of capital grants for secondary refining capacity, funded by a virgin material tax as described in the previous section. Additional research into new technologies to sort, process and upgrade expected future lower grades of copper scrap is also necessary.

In view of the above analysis the following recommendations to promote the demand for copper scrap are made: firstly, a virgin materials tax should be used to raise the necessary capital for investment in additional secondary copper refining capacity potential. The magnitude of this tax should be designed to repay the capital involved in a period commercially acceptable to the government. Secondly, research and development into new technologies to collect, sort and process likely future low grade copper scrap should be provided to make the secondary copper industry more competitive.

6) Incentives to scrap copper users could involve one or both of the following measures to promote demand for copper scrap: Firstly, direct or indirect subsidies on the use of recycled copper as opposed to virgin copper could be made. For example, the government could specify a

minimum scrap copper content for a wide range of copper goods in a similar way to which HMSO has specified the waste paper content (58) of its purchases. By doing this, supplying firms would have to develop processes to comply with government requirements which could then be applied to products for other customers. Alternatively, a tax allowance (e.g. lower VAT rating) could be applied for goods containing more than a certain percentage of copper. In both cases, close monitoring would be necessary to ensure that already recovered copper scrap was not being diverted to certain users who were then claiming the tax relief.

Secondly, the government and/or the UK copper industry could operate a buffer stock scheme for scrap copper. Such a scheme would provide a steady flow of scrap copper at a stable price, so overcoming a common reason given for lack of investment in secondary copper utilisation facilities (169) and would prompt copper users to move away from the volatile primary market to a stable UK scrap market. The buffer stock, probably operated by a government agency, would accummulate copper scrap at times of low demand and resell this copper at times of high demand. Care must be exercised to ensure that imports of copper scrap from other EEC countries are not allowed to disrupt the buffer stock scheme, although scrap imports may be required at times of high scrap demand to supplement UK supply. The mechanisms of import control are beyond the scope of this project and will not be discussed further here.

The costs of operating a buffer stock scheme are unclear although a scheme existed for primary tin and schemes are often proposed for the widely fluctuating waste paper market. The size of stocks held is important, the International Tin Agreement failed because it was unable to halt huge price increases because of limited stocks. Estimates of the necessary stocks and cost of a copper scrap buffer stock scheme may be made by examining the historical fluctuations in old scrap demand. During the low scrap demand period, 1971-1976, a buffer stock would have had to purchase approximately 50,000 tonnes of old scrap at an average price of say £1000/tonne. This would require £50 million which could be used in other interest earning investments. Unless the scheme can be operated at a significant profit, dependent upon difficult to determine accurate long-term price forecasts, this money could be better employed elsewhere. Alternatively, the virgin material tax proposed earlier could be used to finance the buffer stock scheme. This could divert money in the next five years away from the proposed investment in secondary refining capacity and instead a joint programme, using disposal or virgin material taxes, to finance secondary refining plant over the next five years and then the establishment of a copper scrap buffer stock scheme may be required.

In view of the above analysis, it is recommended that a lead should be provided by the government by specifying the scrap copper content of goods purchased by government agencies. It is also recommended that the virgin material tax specified earlier should be used to establish a scrap copper buffer stock scheme to provide a stable supply of copper scrap to the UK scrap consumers at a steady price. The costs and mechanisms of such a buffer stock scheme are unclear and a more detailed analysis is necessary before definite recommendations about the size and buying and selling policies of any scheme can be made.

11.4 Summary to Chapter 11

A policy to promote demand for copper scrap will have to be part of an overall strategy for resource management as no single material is likely to be singled out for special treatment.

At present the UK does not have any formal policies on recycling, although informal methods are employed. This is in contrast to some European countries where specific policies are in operation.

Recommended incentives for increasing demand for copper scrap are subsidies of up to £67 million for secondary refining plant and/or regulations to specify the minimum quantity of copper scrap in goods. Further stimulus for encouraging demand should be provided by the development of a UK copper scrap buffer stock scheme, requiring the purchase of £50 million of copper scrap to stabilise scrap copper prices.

The necessary finance for the above schemes could be raised through a £38/tonne virgin material tax on refined copper imports. The economic mechanisms by which this tax could be levied are uncertain and difficult to determine and more detailed work is necessary before specific recommendations can be made. However, particular care needs to be taken to ensure that imports of copper scrap to a buffer stock scheme do not fatally distort the UK copper scrap market and that UK export markets for fabricated goods are not adversely affected.

CHAPTER 12 - METHODOLOGY

In this work a methodology has been developed along a mass balance approach involving inputs, outputs and accumulation in order to examine the potential for resource saving through the recycling of copper. This methodology may be applied to other materials and the primary purpose of this chapter is to provide a framework for other workers and identify possible problems.

1) Using the assessment method developed in Chapter 3, materials worthy of examination may be selected. Alternatively, interest in more specific areas may require reselection of criteria and materials. If a general assessment is to be made, a breakdown by element will be the most practical method. If the worker is interested in a smaller section of industry then a breakdown by SIC code may be preferred. Criteria selection is a complex problem and subjective criteria should be avoided in the early stages. The interrelationships between criteria should be investigated to avoid multicolinearity. A sensitivity analysis should be used to examine changes of emphasis away from the base case.

2) Having selected a material or materials, a qualitative descriptive model of the industry concerned should be constructed using available literature on the size, structure and location of the industry. In particular, the relationship between the primary and secondary sectors should be investigated. This more specialised review should aim to identify the general flows between the major industrial processes in as much detail as possible so as to provide the basic knowledge necessary to interpret available statistics (see (3) below). It is likely to be

necessary to return to this stage if problems in data analysis occur - often the terminology involved is unique to that industry and should be carefully examined. Generally, a particular process will be found to be central to the industry involved (the semi-manufacturers in the case of copper) and a clear understanding of the size, function and history of this process is essential.

In order to examine the effect of change, end-uses of the material in question and the extent of substitution should be examined. Generally no more than a basic breakdown will be possible but historic trends should be noted and potential for future substitution examined.

The work in this section is the basis on which the rest of the project will be built and as much time as necessary should be devoted to a complete understanding of the industry involved, so that time and effort in later sections is not wasted.

3) The qualitative examination of industry structure and flows in the preceding section now permits a quantitative analysis if statistical data are available. Usually, published statistics will have to be used, but development of statistics by the worker is not impossible although time-consuming. Typical sources include government statistics, trade organisations and in particular for metals, the World Bureau of Metal Statistics. Selection of statistical sources should be based upon the detail required and consistency of data much be ensured over the required period. Pre-war and war years data is difficult to obtain and lacking in detail.

A decision about the time interval required between data points will have to be made at this point and will depend upon a balance between data availability and the time horizon for the work. If the worker is interested in scrap supply for example, the longest lifetime of the goods involved will determine data requirements. In this work annual data was used but monthly or quarterly data is available for more recent years. The flows to and from the central process identified earlier should be determined in as much detail as possible. Data on process efficiencies should be included when possible but these may be difficult to obtain. Published statistics should be examined to determine whether gross or nett values are used, as this could prevent completion of an overall mass balance. Workers should not hesitate to question the validity of published estimates.

Using the statistics developed above, both a "snapshot" of flows in any one year and trends in a single flow over a number of years may be analysed. This can provide valuable information on turning points necessary to adequately model the flows involved.

4) Available studies in the area of interest should be examined to draw upon other workers experience. Care should be taken to ensure statistical compatability between workers and at the same time, a basic review of modelling methods should be made and, depending upon the time horizon, speed and regularity, detail and relevance and data requirements (see Section 6.2), one of three basic modelling methodologies: causal, time series or intuitive may be adopted. In this study potential turning points were of particular interest as previous models had assumed that historic trends in supply and demand would continue and causal modelling was selected. A complete causal econometric

model is unlikely to be possible unless detailed data on stocks, in particular, is available. Instead, individual equations of an econometric model will probably have to be constructed. The volume of data involved and the probable use of regression techniques means that a working knowledge of computing and statistics is essential.

5) The price of a commodity is often quoted as the driving force between supply and demand and an understanding of how the market price is established is necessary. In particular, it is necessary to establish whether the price is set by the free market or by the suppliers. Alternative markets and hence market prices may be available and an examination of the interrelationships between these markets is necessary. The real price of a product over a period of time will be required and various deflation indexes should be investigated. The relationship between primary and secondary prices needs to be evaluated and any discrepancies identified.

6) Having selected a modelling technique and established a statistical base on which to evaluate various models, the demand for the commodity in question, measured by flows from the central process identified in (3), should be examined. This serves two purposes; firstly, if the models developed are unsuccessful then modelling of the less detailed flows is also likely to be unsuccessful and, secondly, historic and future demand levels will govern the supply of discarded goods onto the market.

It will be found that demand can be measured at a number of points and in various ways. Selection of a measure of demand depends upon data availability and the desire to measure aggregate or disaggregate demand.

Historical trends in demand in terms of consumption per capita or in relation to industrial production should be examined, although care must be taken not to rely too heavily upon the data obtained if turning points have, or are, about to occur.

Other published models (probably of US origin) should be examined to identify factors and methods applicable to the UK. Selected dependent and independent variables should be evaluated and a model specification generated and evaluated. The effect of stock changes masking true demand should be examined carefully although, as in this project, general industrial stock changes may have to be used. The adaptive expectations modelling method was found to be particularly applicable and other workers are recommended to employ this factor in their models. Industrial production has historically been an important factor in demand but this may no longer be true for certain materials. Alternative activity level indicators should be employed always remembering that forecasts of these indicators and other variables are necessary before accurate forecasts of demand can be made. The central role of the price of the material involved and the price of substitutes means that they should also be included in the model specification. Time lags in the various variables should be included in the model specification.

Permutations of the model specification should be examined using regression analysis and a model selected on statistical grounds although, as in the case of copper goods demand, subjective analysis is also necessary to produce an acceptable model(s). If doubt exists in the selection of a model then alternative models should be proposed and their effect investigated in the relevant sections.

7) The supply of secondary materials is difficult both to measure and model. In the case of secondary copper supply, no published statistics were available and instead calculated old scrap withdrawals were compared with calculated old scrap arisings.

The various methods and implications of assessing secondary material supplies needs to be examined and their relevance to the aims of the project identified. Generally, a historic time-series for fabricated goods consumption less dissipative uses needs to be developed from the earlier statistical analysis and compiled with end-use and lifetime estimates (developed from published sources, although specific commodity estimates may be constructed with difficulty) to provide an estimate of the volume of potentially recoverable secondary material available. By comparing this estimate with actual secondary material withdrawals a recoverability factor may be determined for use later in forecasting secondary material supply. Additionally, the size of a semi-permanent pool of secondary material may be determined and its effect upon scrap supply examined.

8) Having modelled overall goods demand and secondary material supply it is now necessary to examine secondary material demand. Generally, the methodology in (6) above should be followed and only the aspects pertinent to secondary material demand will be discussed here.

The mechanisms of secondary material demand are not easily understood or modelled. A wide range of factors could influence demand measured by either total or disaggregated dependent variables. In the case of copper two models of total scrap demand were constructed; a price independent and price dependent model. Depending upon the degree of integration between the primary and secondary industries demand for fabricated goods may already incorporate many of the factors considered to affect secondary material demand - so producing price independent models. As in the case of total goods demand an adaptive expectations model may be found to be a useful tool, while new secondary material generation, measured by the previous years total demand may also be relevant.

Modelling disaggregate secondary material demand may not be as successful as modelling total demand although this may be largely due to the inaccuracies in the statistics in the flows described in (3). A more subjective assessment of proposed models is necessary to ensure that unreasonable combinations of independent variables are rejected - as should variable coefficients of the wrong sign or magnitude - to enable the construction of a subjectively and statistically acceptable models.

9) The next step is forecasting flows using the derived models. In order to do this, it is necessary to obtain forecasts of the independent variables and reference to specialised published studies should be made or, in some cases, crude extrapolation of historic trends used. Uncertainty can be accounted for by carrying out a sensitivity analysis. Risk analysis techniques using Monte-Carlo simulation can be helpful. Independent variable should be included in a sensitivity analysis and low, base and high forecasts of the dependent variable made. Trends in the dependent variable should be investigated and their effect upon other flows assessed. For example, the downturn in copper goods demand is expected to continue as economies of use, miniaturisation and substitution by other materials continue. These trends will have a significant impact

upon old copper scrap supply and demand and identifies this particular area as worthly of further investigation.

It may be found that future goods demand will not be linked, as in the past, to general economic indicators and the reasons for this will have to be investigated.

Secondary material supply will probably be largely independent of goods demand forecasts but highly dependent upon the lifetime of the goods involved. Secondary material demand in contrast, will be highly dependent upon goods demand forecasts and possibly upon forecasts of the other independent variables. In the case of copper, the price dependent and independent models gave similar results and were used, with the forecasts of goods demand, to predict old scrap demand. By comparing old secondary material supply and demand any imbalances may be identified and the effect of any potential savings on imports assessed. The cost of any increased recovery effort may be determined by calculating the investment and operating costs necessary which should costs compared with national and corporate benefits. This is a complex area and care must be taken to ensure that all relevant factors are considered.

10) Finally, a range of policy options should be examined and pertinent policies specified. Such policies are likely to be part of an overall resource management programme and their overall effect on the nation as a whole and, in particular, on related industrial sectors assessed. Existing regional policies need to be examined and their relevance assessed.

Generally, a number of policies will be available to promote the supply of secondary amterials, but few to increase demand. Depending upon the conclusion reached in (9) relevant policies should be selected after considering the complex problems of process economics and social costs of each option.

Many policies will be general in their application, while others may be specific to certain industrial sectors and care must be exercised to ensure that cross-linkage effects on other sectors are not overly detrimental.

CHAPTER 13 - DISCUSSION

Owing to the complex and closely interrelated nature of this work the major steps in the development of the project are summarised before proceeding to the final conclusions.

The widely held view of many resources being totally depleted in our lifetime was examined. If historical trends continue in an exponential manner, then existing and future reserves are unlikely to satisfy demand without major or even traumatic changes in current attitudes.

Recycling can help to alleviate the problems of exponential growth and provide the additional benefits of energy savings, lower investment costs, a reduced volume of waste for disposal, a benefit to the Balance of Payments and a strategic supply of raw materials. Possible disadvantages could be increased local (UK) pollution levels and increased processing costs. The effect of increased recycling activity upon the time to exhaustion of resources is limited because of the dominating influence of exponential growth. However, there is cause for some optimism for changes away from historical patterns of consumption in the developed countries.

The alternatives and/or complements to recycling are increased extraction efficiency of primary materials; more efficient utilisation of materials (with product life extension offering the best hope); substitution of readily available materials for scarce ones; and changes in product design.

The UK as an industrialised nation relies heavily upon exogenous raw materials as it has few natural resources of its own. This lack of natural resources makes the UK largely dependent upon raw materials whose price is governed by supply and demand relationships operating outside the UK. Additionally, the UK is susceptible to supply interruptions. In Chapter 3 a detailed quantitative assessment of the significance to the UK of all raw materials is made to determine those materials to which research effort should be directed. Copper, aluminium, iron and oil are identified as being of particular importance and copper was selected for further investigation. Further analysis indicated that some specific materials, notably paper and lubricating oil, show a surprising potential for benefit from increased recycling effort.

Copper formed the focus of attention of the rest of this work. The generalised flow of copper through the UK is described in Chapter 4 prior to an analysis of the available statistics. The manufacturing processes employed in the various sectors of the copper industry are described and it was found that the secondary copper industry has a more flexible structure which enables it to process a feedstock which is more variable in physical and chemical composition than the primary industry. The end uses of copper are described although there is some difficulty in clearly specifying the quantities being directed to the major end uses. The size and extent of substitution for copper was analysed with aluminium being the principal historical substitute although optical fibres, plastics and ceramics are expected to compete in the future. Finally, Chapter 4 examined the capacity and geographic location of the major sectors of the UK copper industry.

Lack of available data on the end-uses of copper made accurate measurements difficult and this problem was also experienced in assessing the capacity levels of the UK copper industry. This does not severely limit to applicability of the estimates obtained but both areas are worthy of a more detailed analysis.

Chapter 5 focusses on development of a quantitative description of the industry using a statistical analysis of data in published sources. These sources are readily available for post-war years (1949-1976) but little information was available for pre-war and war years (1922-1948) and reliance had to be placed on rough estimates. Insufficient detail was found in available statistics to be able to close the loop of copper production, consumption and recycling, without making major assumptions concerning process efficiencies. In particular, the direct-use of scrap, a major copper scrap flow, had to be calculated rather than measured. This is an important area for further work. These statistics are useful to describe UK copper flows at any point in time or to determine trends over a period of time.

Some contrary trends to World patterns emerged around 1960/1962 which could signal a turning point for the copper industry in the UK. The long lifetime of many copper goods will ensure a more than adequate supply of scrap for the foreseable future (i.e. up to 2000).

The problems of accurately measuring UK copper flows are severe. Although the analysis presented in Chapter 5 is the most detailed available over the period in question, statistics on specific areas, notably on scrap flows, need to be developed. The limitations imposed due to data inaccuracies have repurcussions throughout the rest of the work, but do not invalidate the results obtained.

With acceptable qualitative and quantitative descriptions of the UK copper industry available, an examination of available modelling techniques was carried out in Chapter 6 to select appropriate methodologies. This resulted in the selection of a relatively simple causal model consisting of individual regression equations without producing mutually exclusive solutions. Complete econometric models cannot be constructed because of the data limitations, particularly in respect to copper stock changes. The modelling technique selected was also limited by the historic time series of various copper flows available.

Copper price is an important variable in modelling the UK copper industry because it acts as the driving force between supply and demand and for this reason the opportunity was taken to discuss this independent variable separately. The LME price of refined copper was selected as the most suitable after a careful analysis, not only because it is a world market clearing price, but also because it was identified as the major influence on the price of UK imports of refined copper. This price was deflated by the index of materials and fuels wholesale prices.

The LME price of copper reflects global supply and demand imbalances and growth rates of more or less than 5%/annum destabalises copper prices. If the apparent UK trend away from the historical link between industrial production and copper consumption extends to a global effect then future copper prices are likely to be unstable. A close correlation between refined and scrap copper prices was identified which overcomes problems of definition of scrap prices - which could have seriously affected the accuracy of the models producted. The economic theory of copper price evolution has been examined but the modelling of copper prices is declared to be beyond the scope of this project and instead, reference is made to published projections.

In Chapter 7, UK demand for copper goods, measured by the consumption of semis by the fabricators was modelled. The models were developed by examining other work and included the following parameters:

1) The lagged dependent variable
2) The index of industrial production
3) The price of copper
4) The price of aluminium
5) Current and lagged general stock changes

The lagged dependent variable was included, together with the price of copper, as the proposed model was expected to be of the adaptive expecations type where current demand is a function of the difference between last years demand and the long-run equilibrium demand, itself a function of price. The results showed that UK copper flows could be successfully modelled in this way. The index of industrial production (taken to indicate activity level) has been traditionally or conventionally included in copper demand models.

The models selected from the 300 proposed models of total, unalloyed and alloyed semis consumption were highly successful (with r^2 values typically about 0.9) and included four common variables. These were - the lagged dependent variable, the real price of copper the previous year, the real price of aluminium the previous year and deflated current materials and fuels stock changes. The model of the stable alloyed semis consumption did not include the index of industrial production and alternative models, including and excluding this variable, were developed for total and unalloyed semis consumption. The industrial production independent models of total and unalloyed semis consumption were more accurate over recent years and this is a strong indication that the link between copper demand and industrial production was broken in the mid-1960's. Only by analysing data over the next few years will it be possible to positively identify whether this is true or whether an alternative activity level index should be included.

The limitations imposed by this concern over model structure meant that both types of model were used to forecast future copper demand.

The low, base and high forecasts of UK copper semis demand up to the year 2000 show growth rates of -0.9, +0.5 and +2.5% per annum respectively. These forecasts differ significantly from forecasts produced by other workers who generally include industrial production in their models, but do agree with a crude extrapolation of the trend over the past eleven years. These low forecasts of copper demand are not only due to a break in the link with industrial production but are also due to expected increased energy costs for copper so raising real prices, increased substitution for copper by not only aluminium (as the gap between aluminium and copper prices is expected to close) but newer materials such as optical fibres and plastics. Economies of use, reducing the amount of copper per good produced are also expected to contribute to the downfall in copper demand. The inclusion of variables to cover these developments in the models of copper demand already constructed is not practical.

Copper scrap supply was then modelled in Chapter 8, by comparing potentially recoverable annual scrap arisings with calculated old scrap withdrawals. This was done by applying average lifetime estimates for copper goods (obtained from published sources) to the end-use estimates from Chapter 4 and the time series for the final consumption of copper goods (developed in Chapter 5) after a 5% allowance for dissipative uses. Over the period 1956 to 1976 (the earliest time period for which data was available), an average of 52% of annual potentially recoverable scrap arisings was recycled as old scrap with the balance of 48% contributing to a semi-permanent pool of copper scrap. This pool was estimated to contain 2.6 million tonnes in 1976.

The estimates produced for annual scrap arisings are only rough; final consumption, lifetime and end-use data limit the examination to an indication of overall trends in scrap supply. Nevertheless this is an important factor in assessing future scrap supply and demand scenarios.

Using the final consumption data from Chapter 5 and forecasts from Chapter 9, future scrap supplies are expected to rise by 20% from the 1976 value of 280,000 tonnes/year to 330,000 tonnes in the year 2000.

Models of total and disaggregrate scrap demand measured by the total scrap collected, the direct use of scrap and the production of secondary refined copper were developed in Chapter 9. Once again, the adaptive expectations model proved successful.

Approximately 300 forward and backward additive or subtractive causal models were developed by adding or removing variables to a starting list of variables until no further improvement was found. Model selection was more complex than in the case of copper demand and was often made on a subjective interpretation of the model structure as well as the statistical tests employed.

The independent variables selected included current and lagged values of the following:

1) The lagged dependent variable
2) Total semis production
3) Unalloyed semis production
4) Alloyed semis production
5) The real price of copper
6) General industrial stock changes
7) The percentage of UK refined supplies from nett imports of refined copper
8) Annual potentially recoverable scrap arisings
9) A collection costs index (= LME price copper/index of labour costs)

Models were constructed employing various combinations of these variables.

Two models of total scrap demand are proposed. The first is a price independent model indicating that scrap demand is a function of lagged demand and various semis production indicators which are themselves a function of copper price (Chapter 7). This model has a higher r^2 value than the second, price dependent model, which relates scrap demand to lagged demand, semis production the previous year and the current and lagged price of copper. There is no conclusive evidence for either model being more acceptable and it was therefore decided that total scrap demand is a function of both the price independent new scrap generation and the price dependent old scrap supply.

Although the models produced are not true econometric models and are limited by inaccuracies in the available data, they are the best models known to be available at present in the UK and are a significant step forward in modelling scrap demand. If any of the limitations described above can be removed, even more accurate models may be constructed, but particular emphasis should be directed to the direct use and secondary refined copper models whose structure is suspect.

The models developed in earlier Chapters were brought together in Chapter 10 to forecast future developments in scrap supply and demand. The forecasts obtained indicate that total scrap demand will rise or fall dependent upon the copper demand scenario employed. By using the copper goods forecasts also developed in Chapter 9, new scrap generation and old scrap supply estimates can be made. Comparison of potentially recoverable old scrap supply and demand forecasts shows that under the most likely scenario of declining copper goods demand, the potential to utilise an extra 100,000 tonnes/year of old scrap by the year 2000 exists. Additional to this volume of likely recoverable old scrap, another 116,000 tonnes/year of possibly recoverable old scrap may also potentially be recoverable in the year 2000. This would make the UK virtually self sufficient in copper supplies particularly if withdrawals are made from the 2000 pool of potentially recoverable scrap of about 7 million tonnes. International trade in copper cost the UK £273 million in 1974, mainly due to imports of refined copper valued at £314 million. Using the above forecasts of likely and possible old scrap recovery levels, a Balance of Payments saving in 1978 prices of up to £181 million is possible.

The recovery of the old scrap identified above would probably be in the form of low grade scrap owing to miniaturisation and economies of use. Direct use of higher grade scrap will continue, but a need for an increased UK secondary refining capacity capable of handling the increased volume of low grade scrap was identified. The necessary investment would be £67 million in 1978 terms to recover an additional 100,000 tonnes/year of copper in scrap by the year 2000.

Concern over model structure and data inaccuracy, combined with potential changes in future scrap grades meant that no forecasts of the direct use of scrap or the production of secondary refined copper were believed to be meaningful - although this is an area worthy of further investigation.

Although the above estimates are only approximate and are limited by the accuracy of the models used and forecasts of the independent variables, they do indicate that a significant potential exists for increased old scrap recovery. The policies needed for realisation of this potential are discussed in Chapter 11. It is suggested that a policy for increased old scrap recovery should be part of an overall resource management programme. At present the UK does not have a formal policy on either recycling or resource management. Of the fiscal incentives available, the majority promote the supply rather than demand for low grade copper scrap, which is not helpful to the UK copper industry unless this material is refined to pure copper for mainly electrical uses.

The fiscal incentives that would tend to increase demand for copper scrap are a direct subsidy of up to £67 million in secondary refining plant and regulations to specify the minimum quantity of scrap copper in new goods. In both cases, available statistics need to be further developed to enable the additional old scrap used to be identified. A UK buffer stock scheme is proposed for copper scrap requiring an initial investment of approximately £50 million. The scheme should be operated by the government and the copper industry to ensure a steady supply of stable priced copper scrap to consumers, so promoting demand. The effect of EEC legislation on trade barriers needs to be further investigated to determine effect of copper scrap trade within the EEC on the buffer stock and refining schemes proposed.

The above proposals may be financed by a virgin materials tax equal in 1976 to £38/tonne on imports of refined copper to the UK. The economic mechanisms by which this tax could be levied are uncertain and difficult to determine and more detailed work on this and the other policies proposed is necessary before more definite recommendations can be made.

CHAPTER 14 - CONCLUSIONS

Recycling has been identified as a means of reducing the problems of exponential growth upon World mineral supplies. Alternatives to recycling include increased primary extraction efficiencies, more efficient utilisation of existing resources through product life extension, economies of use and miniaturisation. However, if historic exponential growth patterns continue these measures merely delay the time to exhaustion of materials by a few years.

An assessment of the significance to the UK of all materials resulted in the selection of copper as a material worthy of further investigation.

A comprehensive qualitative and quantitative analysis of the UK copper industry has been carried out. Acceptable models for explaining and forecasting aggregate and disaggregate copper goods demand and the supply and demand of copper scrap have been proposed and used to forecast copper goods demand and the supply and demand for copper scrap up to 2000 under various scenarios. Without incentives some modest growth in copper goods demand will occur at best, but it is more likely that miniaturisation and economies of use will cause a decline in copper goods demand. The effect of such a decline on copper scrap supply and demand would result in the potential to increase the usage of old copper scrap per unit of semis produced.

With appropriate policies, more could be done to encourage recycling with total potential savings to the UK of £65 million/year up to 2000 (at 1978 prices) at a total cost of £67 million spread over five years. Under a high scrap recovery scenario it would be possible for the UK to become self-sufficient for a limited time in copper supplies, particularly if withdrawals from the pool of potentially recoverable old copper scrap are made. This could save the UK £181 million/year on the Balance of Payments.

A global energy saving of 90 GJ/tonne would accrue but at the expense of UK expenditure of 30 GJ/tonne. More positive policies are required both for direct actions (investment grants in secondary refining plant) and indirect actions (specifying minimum scrap copper content of fabricated goods) in order to realise the potentials identified in this thesis. Additionally, a UK scrap copper buffer stock scheme should be set up to provide a steady supply of stable priced scrap copper to industry. The above policies could be financed by a virgin materials tax of approximately £40/tonne on imports of refined copper.

RECOMMENDATIONS FOR FUTURE WORK

Recommendations for future work, broken down into various sub-sections, are given below, together with cross references to relevant sections of this thesis. Some carry over of recommendations between sub-sections is inevitable and excessive duplication has been avoided whenever possible.

General Recommendations

1. Using empirical data, the effect of S-shaped growth patterns upon SLI and ELI estimates should be investigated (Section 2.6.3).
2. Substitution mechanism should be examined in more detail as should the effect of future substitution patterns upon existing by-co-product relationships (Section 2.6.2.3).
3. More authoratative data on investment costs for secondary material processing plants should be developed (Section 2.4.3) (see also 42 and 43).
4. The interrelationship of pollution control measures between the largely UK exogenous primary industries and the indigenous secondary industries needs clarification (Section 2.4.4).
5. Necessary policies to alter consumer attitudes towards recycled goods, possibly by advertising and government leads in procurement policies, are needed (Section 2.4.6).
6. A policy of strategic stockpiling of materials likely to be subject to interruptions in supply needs to be evaluated (Section 2.4.8).
7. More empirical data on the pivate and social costs of recycling is required to define optimum recycle ratios for a range of materials (Section 2.5).

Significance of Materials

8. A breakdown of selected areas by SIC code, not by element, should be carried out, possibly by using input/output tables. This will

enable the importance of specific areas of industry to be assessed (Section 3.3).

9. Subjective criteria would make the assessment method used more flexible and such criteria should be included in the list of criteria used, although this will require a great deal of careful analysis (Sections 3.4 and 3.5).

10. A further analysis of the effect of changes in the criteria values and their relative importance should be carried out to investigate likely future changes. e.g. the effect of energy price increases (Section 3.11).

11. The assessment procedure developed in Chapter 3 should be repeated using 1981 data and an analysis of any significant changes made.

<u>Additional data requirements</u>

12. An exhaustive commercial survey of the UK copper industry is required to determine the size, geographic location and extent of vertical and horizontal integration of the companies involved. The capacity expansion or contraction plans of the companies included in the survey should be identified and the effect upon UK copper scrap demand and the more diverse scrap metal merchants examined (Sections 4.2 and 4.4).

13. UK copper statistics should be broken down into quarterly or monthly periods and the size and nature of any time lags in the flows identified (Section 5.2).

14. The process efficiencies of various copper processing operations, and in particular the secondary refiners and fabricators, should be assessed so as to provide more accurate information on scrap consumption (Sections 5.3.2 and 5.3.5).

15. Reasons for the difference between apparent and actual consumption of refined copper should be identified (Section 5.3.2).

16. Trends in the copper content of alloy shape groups should be determined and used to more accurately describe these flows (Section 5.3.3).

17. Empirical measurement of actual fabrication efficiencies should be made. This will be possible if the scrap statistics recommended in 14 and 19 are developed. (Section 5.3.4).

18. Statistical evidence of copper flows after the fabricators is necessary to identify international trade in copper goods and the final consumption of copper goods in the UK (Section 5.3.4).

19. Reporting requirements on the statistics of scrap flows in the UK should be expanded to include data on new and old scrap flows, the direct use of scrap and the copper content of international trade in scrap. These statistics should include the volume, grade, source and destination of the flows involved. In particular, stock of semis, fabricated goods, refined and scrap copper should be monitored (Section 5.3.5 and 33).

20. The importance of these scrap flows indicates that a government agency should be set up to develop statistics for a wide range of strategically important materials.

21. Although improvements are unlikely, pre-war and war years copper statistics should be examined to enable more accurate forecasts of scrap arisings to be made. In particular, the unusual copper flows of the Second World War should be examined (Sections 5.4 and 5.5).

22. A survey of the end-uses of copper in the UK is necessary. This survey should include the effects of tertiary wiring so providing more realistic estimates of the eventual destination of copper goods (Section 4.3 and 8.5.4).

23. Concurrent with the end-uses survey, the length and form of the lifetime of copper goods should be assessed in more detail and better estimates of dissipative uses made (Section 8.5.5).

24. The geographic location of unrecovered copper scrap should be examined and potential for improved recovery identified (Section 8.7).

Modelling the UK Copper Industry

25. Time series techniques should be applied to the quarterly or monthly statistics recommended for development earlier, to identify cyclical components and their effect (Section 6.2.1).

26. With the more detailed copper statistics compiled from the preceding recommendations it should now be possible to compile a more complete econometric model of the UK copper industry than that developed in this work (Sections 6.2.1 and 6.2.4).

27. The effect of changing UK refined supplies should be investigated so that a relevant copper price can be included in future models (Section 6.3.1).

28. The interrelationship of UK refined and scrap prices should be evaluated and a composite scrap price, reflecting the changing scrap grade pattern, included in future models (Section 6.3.5).

29. UK copper demand should be remodelled using the statistics on fabricated goods consumption recommended for development above (Chapter 7).

30. If modelling of fabricated goods consumption is not possible, then a model of the breakdown of semis consumption should be attempted (Chapter 7).

31. A break from the historic link between copper consumption and industrial production has been proposed. Alternative activity level indicators covering the major end-uses of copper should be constructed and built into future models. In this way, it is hoped that a more complete understanding of the relationship between activity level and copper consumption can be made (Chapter 7).

32. Statistics for other developed countries should be modelled and the extent to which copper demand is now dependent upon industrial production made. Using the results obtained more accurate global forecasts can be made (Chapter 7).

33. The copper stock changes recommended above should be included in future models of copper demand to establish the true demand for copper (Section 7.3.1).

34. Historic substitution mechanisms should be investigated in order to build into future models the effects of the new substitutes for copper and the implications of miniaturisation and economies of use. The extent of quantitative, physical and invisible substitution should be analysed (Section 7.3.4).

35. Using the end-use and life-time surveys proposed earlier, forecasts of potentially recoverable scrap arisings can be made so providing, together with the more accurate statistics on old scrap copper flows recommended earlier, a more complete understanding of the relationship between the supply and demand for copper scrap (Section 8.6).

36. The more detailed statistics on the size, grade and destination of copper scrap flows recommended earlier should enable more accurate models of scrap demand to be constructed. In particular, more accurate models of the direct use of scrap and the production of secondary refined copper should be possible (Sections 9.4.2, 9.4.3, 9.4.4).

37. The extent to which secondary copper is recovered as a by-product of the recovery of other methals should be examined and the results built into future models of scrap demand. (Section 9.4.10).

38. The years for which the models developed in this work was inaccurate should be examined, relevant factors identified and built into future models (Chapters 7, 8 and 9).

The Economics of the UK Copper Industry

39. A detailed analysis of the models proposed for development above should enable the effect of copper prices upon new and old scrap supply and demand to be made and the selection of a price dependent or independent model possible (Chapters 8 and 9).

40. A great deal of further work on the growth in real price of copper and aluminium is necessary to enable accurate forecasts of copper demand and scrap demand to be made. In particular the effect of energy costs, ore grades and pollution control costs needs to be evaluated (Sections 6.3.3, 10.2.2 and 10.2.3).

41. UK and foreign copper demand should be monitored for evidence of the break between industrial production and copper demand and forecasts by other workers should be examined for confirmation of the results of this work.

42. The capital and operating costs of a secondary copper refining plant should be evaluated and the necessary capital investment identified (Section 11.3) (see also 44).

43. The effect of tightening pollution legislation on the operating costs of a secondary copper refinery needs to be evaluated (Section 11.3).

Policies

44. Detailed investment requirements and operating costs for the secondary refining of copper are necessary to develop investment strategies for the UK copper industry (Section 11.3).

45. Increased effort should be devoted to the development of an overall UK resource management policy which will give an incentive to the UK secondary materials industries to invest in modern recovery practices. The effect of such a policy on the UK copper industry should be evaluated (Sections 11.1 and 11.3).

46. A government agency should be set up to monitor increased recovery effort and to make recommendations to the government on policy changes (Section 11.3).

47. An assessment of how investment in the UK secondary copper industry can be effectively used is necessary. The effects of the recommended investment in secondary refining in the UK is also necessary (Section 11.3).

48. The ability of the government to provide a lead in specifying recycled copper content in procurement policies should be investigated and likely effects analysed (Section 11.3).

49. The problems and private and social costs of operating disposal and virgin material taxes needs to be evaluated so that the most effective policy may be selected (Section 11.3).

50. The capital and operating costs of a scrap copper buffer stock scheme should be examined and recommendations made (Section 11.3).

Appendix 1 - Mathematical and Statistical Aspects of Model Formulation

A.1 Algebraic Form of Model

The choice of algebraic form in which models should be expressed may be one of three basic types.

A.1.1 Additive Models

An additive model is expressed in the form:

$$Y = a_o + a_1x_1 + a_2x_2 + \ldots a_nx_n + U$$

where Y = dependent variable

$a_o, a_1 .. a_n$ = coefficient

$x_1 .. x_n$ = dependent variables

U = error or residuals term.

An additive model assumes that the separate independent variables are expected to have an additive effect upon the dependent variable. Additive models are the most suitable type for solution using computational techniques, an important consideration in view of the volume of data to be handled.

A.1.2 Multiplicative Models

A multiplicative model is expressed in the form:

$$Y = a_o x_1^{a_1} x_2^{a_2} \ldots x_n^{a_n} + U$$

which, for ease of computational techniques may be converted to a linear expression by the application of logarithms:

$$\log Y = \log a_o + a_1 \log x_1 + a_2 \log x_2 + \ldots a_n \log x_n$$

(the residual term U will be discussed in Section A.3.3.

Multiplicative models assume that the independent variables have a geometric effect upon the dependent variables.

A.1.3 Complex Models

In some cases the independent variables can have a complex effect upon the dependent variable i.e.

$$Y = a_o + a_1x_1x_2 + a_2x_3x_4 + \ldots.$$

Such complex models are generally difficult to linearise and only models of a simple predetermined form can be analysed. However, complex models are rare in economics and so only specific models will be examined.

At this stage it is not possible to decide upon our particular algebraic form of model and so all three types will be tested for suitability, with particular emphasis on the more common additive and multiplicative models.

A.2 Statistical Criteria for Model Appraisal

Before the relationships obtained through regression analysis of the model selected can be used with confidence, a judgement must be made as to the accuracy and reliability of the regression results. These judgements can be of a qualitative basis i.e. would the relationship expressed be logical according to economic theory and secondly by means of statistical tests to analyse quantitatively the relationships expressed.

There are five common statistical tests used to check the validity of the equation results. They are.

A.2.1 The Standard Error

The formula for calculating standard error is:

$$SE = \sqrt{\frac{\Sigma(Y-Ye)^2}{n-v-1}}$$

where SE = standard error

v = no. of independent variables

n = no. of observations

Y = actual value of dependent variable

Ye = estimate of Y by regression equation.

The standard error is in fact the standard deviation of the differences between the actual values of Y and the values calculated from the regression line (Ye). The bigger the standard error of the estimate as a percentage of the actual value of Y, the less precise the regression equation.

The calculation of standard error assumes a large number of observations and generally 25 observations or more are necessary (110).

A.2.2 The "t" Test or Statistic

The t test pertains to the reliability of the relationship between each independent variable and the dependent variable. The value obtained for the coefficients a_o, a_1 etc. are tested to see if their values are in fact significantly different from zero i.e. did the coefficient occur through chance? The t test is obtained by dividing the coefficient a_n by the standard error of a_n:

$$t = \frac{a_n}{SEa_n}$$

The value of t is then compared against the tables of t values to test for significance at certain significance levels. Usually the 95% significance level is used and if the t test is higher than the figure appearing in the tables, then the coefficient a_n is different from zero at that level of significance.

In general a t test of ± 2 or more tells us that we can be very confident that the value of a_n is not zero providing that more than 15 observations have been made (110).

A.2.3 The Coefficient of Correlation, r

The coefficient of correlation is a general statistical test used to measure the correlation between the variables used. This is especially helpful when it is difficult to establish which of the variables are dependent and which are independent. The coefficient of correlation, r, is obtained from the formula:

$$r = \sqrt{\frac{\Sigma(Ye-\overline{Y})^2}{\Sigma(Y-\overline{Y})^2}}$$

where r = coefficient of correlation

Y = actual value of dependent variable

Ye = estimated value of Y

$\overline{Y}$ = mean value of Y

The correlation coefficient has a value in the range +1 to 0 to -1. If $r = 0$ then there is no relationship between the values of Y and x_n; if $r > 0$ then there is a positive correlation i.e. where increases in the value of Y are associated with increases in the value of x_n; if $r < 0$ then a negative correlation exists i.e. increases in Y are associated with a decrease in x_n and vice-versa. If r is exactly +1 or -1 then a perfect positive or negative correlation exists and in such a case all the data points would lie on a straight line and a standard error of zero would occur.

A.2.4 Coefficient of Determination r^2

The square of the coefficient of correlation (r) is known as the coefficient of determination r^2 and is expressed as

$$r^2 = \frac{\Sigma(Ye-\overline{Y})^2}{\Sigma(Y-\overline{Y})^2}$$

The value of r^2 gives the ratio of the explained variation $(\Sigma(Ye-\overline{Y})^2)$ to the total variation $(\Sigma(Y-\overline{Y})^2$. The value of r^2 lies in the range 0 to 1 with a value of 1 indicating that all the movements in Y have been accounted for by the variables considered i.e. a r^2 value of 0.9075 indicates that 90.75% of the variation in Y has been accounted for (110).

A.2.5 The F-statistic

Although a regression equation could have a fairly high r^2 this could possibly be due to chance. In order to test for this the F-statistic is applied, which shows with X% confidence whether the complete set of regression coefficients are significantly different from zero.

The F-statistic is computed as follows:

$$F = \frac{\dfrac{\Sigma(Ye - \overline{Y})^2}{v - 1}}{\dfrac{\Sigma(Y - Ye)^2}{n - v}}$$

where Y = actual value of Y

$\overline{Y}$ = mean value of Y

Ye = estimated value of Y

v = number of variables

n = number of observations.

If the F-statistic is above the value appearing in the appropriate F-statistic tables, then the entire regression equation is significant and the r^2 value has not arisen by chance. As a general rule(110)a value of the F-statistic of over 6 is significant at the 95% confidence level where the number of observations exceeds six (If the number of observations is less than six, the necessary value of F rises dramatically).

A.3 Interrelationships of the Model Variables

In certain circumstances, several of the statistical tests will be satisfied but others will not. Often this is due to certain effects related to the assumptions underlying the use of least squares methods exerting their influence. The more common effects are described below with methods of identification where possible.

A.3.1 Linearity

Linear regression assumes that the independent variables are linearly related with the dependent variable. If they are not, the r^2 and F-statistic values will be very low. If the model postulated appears logical then the variables may need to be linearised. This commonly involves converting data into its logarithmic form or first difference form. In certain rare cases curvilinear data may be required.

A graphical approach may be adopted to test for linearity by plotting each independent variable against the dependent variable and seeing whether the points lie along a straight line.

A.3.2 Multicollinearity

Multicollinearity exists when two or more of the independent variables are highly correlated and also correlated with the dependent variable. This means that an independent variable would have an unexpected low t-value.

Multicollinearity may be tested for in most computer packages by listing a correlation coefficient matrix where the r values between the independent variables are shown. If two or more variables are highly correlated then any regression equation using these variables will produce unexpectedly low t-test values. Models of this form should be avoided where possible and only one of the correlated variables used.

A.3.3 Homoscedasticity and Heteroscedasticity

Any regression equation should include a residuals or error term, u,

$$Y = a_o + a_1x_1 + a_2x_2 + \dots a_nx_n + u$$

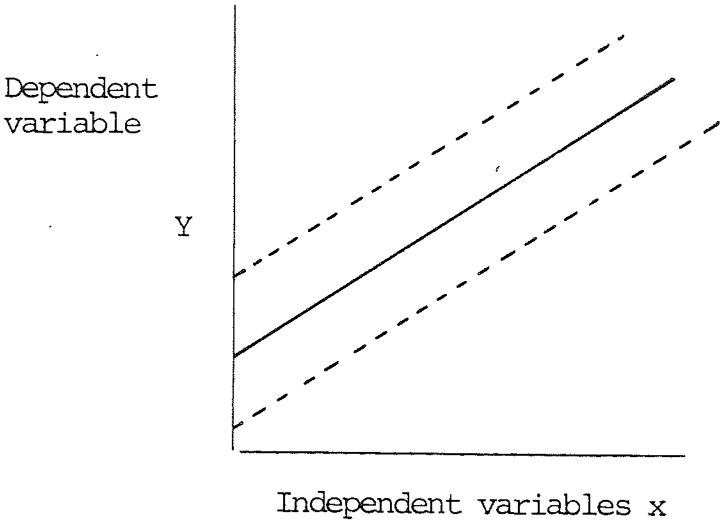
These residuals are the difference between the actual values of Y and the predicted values of Y given by the regression equation.

Homoscedasticity is the requirement that the residuals should have a constant variance. This is shown in Figure A.1a where the scatter of actual observations around the computed regression line is constant. In Figures A.1b and A.1c the error terms are not constant and hence the requirement of homoscedasticity is not met; in this case the variance is technicially known as heteroscedasticity.

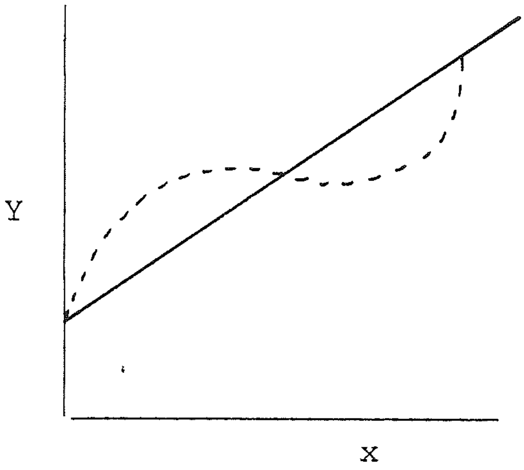
If the residual terms are heteroscedastic then the statistical significance of the regression equation is likely to be small even though the model appears to be logical from an economic or other viewpoint. Heteroscedasticity generally implies that one or more important independent variables are not in the model. The presence of heteroscedasticity can be detected by the Durbin-Watson statistic (which is produced as part of a computer regression analysis package) where the calculated Durbin-Watson statistic is compared to values in tables.

A.3.4 Autocorrelation

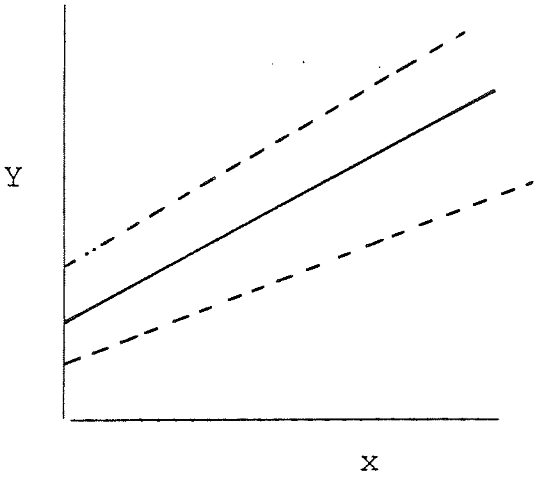
Another requirement of the residuals term in the regression equation is that they can be independent of each



a) Homoscedasticity



b) Heteroscedasticity



c) Heteroscedasticity

Figure A.1 - Examples of Homoscedasticity and Heteroscedasticity other i.e. do not follow a pattern. If successive recordings of residuals are not independent then this is termed autocorrelation or serial correlation. Autocorrelation is often found when the data relating to the variables consists of time-series. Figure A.1(b) shows an example of autocorrelation where there is a clear pattern in the residuals which again suggests that an important variable has been excluded. If it proves impossible to identify this variable then a change in the form of the variables, for example curvilinear, logarithmic or first differences should be tried.

Autocorrelation is identified by the use of the Durbin-Watson statistic, the value of which depends upon the measure of the first-order correlation between the residuals U_t and U_{t-1}. The Durbin-Watson statistic can have the range 0 to 4 with a value of 2 indicating no serial correlation (110).

A.4 Summary

Summarising, the statistical tests for an accurate model should lie within the limits shown in Table A.1.

Table A.1 - Expected Value of Statistical Tests used in Regression Analysis

Statistical Test	Symbol	Expected Value
1. Standard Error	SE	as a % of value of Y, lower the better.
2. t-test	t	> ±2 (assumes > 15Obs)
3. coefficient of correlation	r	-1 to 0 to +1 (nearer ± 1 the better)
4. coefficient of determination	r^2	0 to +1 (nearer +1 the better)
5. F-statistic	F	>6 (assumes >6 obs)
6. Durbin-Watson test	D-W	0-4, as near to 2 as poss.

Appendix 2 - Relevant Prices and Economic Indicators

Table B1 Metal Prices (£/tonne)

Year	LME annual average cash settlement price (85)	LME price deflated by Index of Raw Materials Costs	Aluminium Price (85)	Zinc Price (85)	Lead Price (85)
1949	131	152	96	88	103
1950	176	194	114	119	106
1951	217	176	124	172	162
1952	255	240	156	149	149
1953	247	253	157	75	91
1954	245	252	156	78	96
1955	346	346	167	91	106
1956	324	313	190	98	116
1957	216	207	197	82	97
1958	194	199	184	66	73
1959	234	237	180	82	71
1960	242	245	186	89	72
1961	226	231	186	78	64
1962	230	234	181	68	56
1963	231	231	181	77	63
1964	346	332	191	118	101
1965	461	437	196	113	115
1966	546	506	196	102	95
1967	411	383	200	101	84
1968	517	440	234	111	102
1969	611	503	249	121	123
1970	580	461	256	123	127
1971	437	332	257	127	104
1972	421	306	235	151	121
1973	716	495	244	347	175
1974	877	323	324	528	252
1975	557	188	392	335	186
1976	782	208	491	395	251

Table B2 - Economic Indicators

Year	Index of industrial production (all industries) (1970 = 100) (122)	Stock changes, Materials + Fuel £ million current prices (122)	Stock changes, Materials + Fuel £ million, 1970 prices (122)	Index of average weekly wage rates (manual workers) July 1972=100 (122)	Index of wholesale prices, materials + fuel 1963=100 (121)
1949	53.8	-	-	27.9	69
1950	57.1	-	-	28.9	90.1
1951	58.4	-	-	29.3	123.3
1952	56.6	-	-	34.6	106.6
1953	60.2	-	-	36.1	97.8
1954	63.3	-	-	37.6	97.2
1955	66.4	116	160	40.1	100.0
1956	66.9	81	112	42.7	103.5
1957	68.1	17	23	44.9	104.9
1958	67.5	-97	-149	46.3	97.8
1959	70.9	19	22	47.5	98.7
1960	75.8	224	309	48.7	98.8
1961	76.7	56	69	50.6	97.7
1962	77.4	-71	-86	52.2	97.7
1963	79.7	-1	-13	53.7	100.0
1964	86.5	199	232	56.3	104.1
1965	89.1	108	117	58.4	105.4
1966	90.6	19	10	61.2	108.0
1967	91.7	-6	-17	63.6	107.5
1968	97.2	92	102	68.4	117.3
1969	99.9	82	87	72.1	121.4
1970	100.0	113	113	79.4	126.0
1971	100.3	-152	-146	89.3	132.0
1972	102.5	-45	-41	101.5	137.0
1973	110.0	386	303	114.6	182.0
1974	106.9	489	287	134.3	271.0
1975	101.7	-791	-391	174.4	297.0
1976	102.3	-133	61	209.0	377.0

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