THE METAL-WORKING MACHINE TOOL INDUSTRY IN ENGLAND, 1850-1914, WITH SPECIAL REFERENCE TO GREENWOOD AND BATLEY LTD.

BY

RODERICK C. FLOUD.

BODLEIAN LIBRARY OXFORD
DEPOSITED
THESIS
9-i-71

(mt 1220)



ABSTRACT

The machine tool industry is one of several branches of the engineering industry which developed as a manufacturing industry during the second half of the nineteenth century. It is perhaps the most important of all the capital goods industries, since its products are used by, and are indispensable to, all other industries processing metals. The production of industrial machine tools thus made possible the considerable advances in the use of metals which took place during the nineteenth and twentieth centuries, on which much of modern industrial society is based.

This thesis is the first attempt to write a comprehensive economic history of the English machine tool industry during the period of its transition from a craft, or handicraft, industry to a full manufacturing industry. Professor S.B. Saul has discussed the industry, largely from the standpoint of individual firms, in several articles, but there has been no other extended treatment of the industry.

Two separate lines of approach to the history of the machine tool industry are used. Firstly, the growth and performance of the industry is analysed in aggregate terms, principally through two major statistical sources, which have not previously been used in such a way, the trade directories of the period and the statistics of the imports of machine tools into France, a major customer for the machine tools of Britain and her competitors. It is argued that the machine tool industry can only be understood within the context of

the engineering industry as a whole, and the relationships between the manufacture of machine tools and other metal goods is investigated. The size of the machine tool industry, in terms of the number of firms making machine tools at any one time, is shown to be directly related to the fluctuations in the demand for machinery within the domestic economy. The success of the industry is considered in relation to American and other foreign competition, and it is argued that simplified explanations of English decline and American growth as producers of machine tools do not accord with the chronology of competition which is established. Possible explanations are then explored for the changes in the competitive position of English exporters and producers of machine tools.

Secondly an analysis is made of the experience of one machine tool producer, Greenwood and Batley, to provide information on characteristics of the industry which could not easily be approached through aggregate analysis. The very extensive cost and sales records of the firm, covering all its production between 1856 and 1900, are used in this study. The market for one of the principal products of the firm, machine tools for the production of small-arms, is described in detail, and the sales made by the firm are analysed and its pricing policies investigated. The production of machine tools by the firm is considered through an analysis of changes in productivity; it is argued that the productivity of labour employed by the firm was increasing at a substantial rate throughout the period of analysis, and that this can

largely be explained by the effects of technical change in the industry. The implications of this rise in labour productivity for the machine tool and engineering industries as a whole are also briefly considered.

Throughout the thesis, the major emphasis is placed upon the use of statistical sources and techniques in writing the history of the industry. This emphasis, together with considerations of space and time, prevented more than incidental reference to some aspects of the industry, principally the experience of its labour force. Because of the imperfections of the evidence, it was impossible also to discuss trends in output or prices for the industry as a whole. As a counterweight to this, three major sources of statistical evidence on the industry, trade directories, trade statistics, and the records of Greenwood and Batley, have been analysed in detail. Computer data processing and analysis methods were used to enable those records to be utilised, and the value of this type of approach to the writing of economic history is discussed.

TABLE OF CONTENTS.

Preface		1
Introduction		2
Ch. 1	The Technical History of Machine Tools, 1850-1914	18
Ch. 2	The Structure of the Machine Tool Industry	39
Ch. 3	Characteristics and Growth of the Machine Tool Firms	106
Ch. 4	The International Trade in Machine Tools	144
Ch. 5	Greenwood and Batley: Markets and Prices	235
Ch. 6	Greenwood and Batley: Production	349
Conclusion		402
Bibliography		408

Preface.

Many members of firms in the machine tool industry have helped me during the course of my research. In particular, I should like to thank Mr. R.C. Bragger and Mr. J.T. Clements of James Archdale and Co. Ltd., Mr. D. Mitchell and Mr. G.C. Butler of the Butler Machine Tool Co. Ltd., Mr. J.H. Hartopp, Mr. J.D. Ellson and Mr. J. Hugo of Alfred Herbert Ltd., Sir Stanley Harley of Coventry Gauge and Tool Co. Ltd., and Mr. R. Gibson of A.A. Jones and Shipman Ltd. Others connected with the industry who have given me considerable help include Mr. H.C. Barrett of the Machine Tool Trades Association, Mr. P.A. Sidders of Machinery and Mr. F.G. Barkway of Kelly's Directory of Merchants and Manufacturers. I should also like to thank Mr. Ian Hollick for permission to use the papers of Sir Alfred Herbert in his possession.

Much of this work would have been impossible without the help of Greenwood and Batley Ltd., and in particular of Mr. L. Haberman and Mr. Charles Greenwood. The archives of Greenwood and Batley have now been deposited with the Leeds Central Library (Archives Department) and I should like to thank Mr. Collinson of that department for his help.

Nuffield College, Oxford, and the Central Research Fund of London University, made grants in aid of this research, for which I am very grateful.

Professor S.B. Saul, Dr. R.M. Hartwell, and Professor N. Rosenberg discussed the industry with me at various times, and I am grateful to them for their help and advice. My main debts however are to my supervisor, H.J. Habakkuk, for his constant help and encouragement, and to my wife.

INTRODUCTION.

The growth of the machine tool industry during the nineteenth century made possible the immense expansion in the use of metals which has been a major characteristic of modern industrial civilization. Without machine tools, it would have been impossible to have exploited the possibilities of the use of machinery in industry. The machine tool industry is thus the most central and the most important of the many engineering industries, for its products are indispensable equipment for all engineers.

In spite of its importance, the machine tool industry has not received extended treatment from economic historians. The attention which it has received has largely been with reference to two problems of economic history, the problem of the difference between American and British technology in the nineteenth century, and the issue of the supposed decline in the competitiveness of British industry in the last quarter of that century.

Machine tools as a factor in the development of British and American technology in the nineteenth century were considered by H.J. Habakkuk in his book of that name,[1] and they have also been considered in this way by Nathan Rosenberg in his edition of the Whitworth-Wallis reports,[2] and in his article with

1 Habakkuk, H.J. 'American and British Technology in the 19th Century' (Cambridge U.P., 1962)

2 Rosenberg, N (ed) 'The American System of Manufactures' (Edinburgh U.P., 1969)

E. Ames on the Enfield arsenal.[1] Rosenberg has also discussed the industry at length in an important article on technological change,[2] and one of Rosenberg's main points about the 'spin-off' in technology from improvements in machine tools has been recently documented from the British evidence on the armaments industry by Clive Trebilcock.[3]

The 'Great Depression' and machine tools were first considered by D.L. Burn in his article on the genesis of American engineering competition,[4] and this has been more recently followed by Professor S.B. Saul in an article on the market and the mechanical engineering industry at this time,[5] and in his contribution to larger work on British industry and foreign competition.[6]

1 Rosenberg, N. and Ames, E. 'The Enfield Arsenal in Theory and History', Economic Jnl., LXXVIII, 312, Dec. 1968, pp 827-842.

2 Rosenberg, N. 'Technological Change in the Machine Tool Industry, 1840-1910', Jnl. of Economic History, Dec. 1963.

3 Trebilcock, C. '"Spin-off" in British Economic History: Armaments and Industry, 1760-1914', Econ. Hist. Rev. XXII 3, Dec. 1969.

4 Burn, D.L. 'The Genesis of American Engineering Competition, 1850-1870', Economic History, Jan. 1931.

5 Saul, S.B. 'The Market and the Development of the Mechanical Engineering Industries in Britain, 1860-1914' Econ. Hist. Rev. XX, 1, April 1967.

6 Saul, S.B. 'The Engineering Industry', in Aldcroft, D.H. (ed) The Development of British Industry and Foreign Competition, 1875-1914, (London: Allen and Unwin 1968)

The only consideration of the machine tool industry itself is also by Professor Saul, who discusses the growth of the British industry after 1870.[1] The article relies for its evidence largely upon business records, and the history of the industry is thus approached very much through the histories of the major component firms, through some contemporary engineering periodicals, and through a number of minor statistical sources. Although Professor Saul has produced illuminating evidence on the history of the major firms, he was constrained by considerations of space and time from examining the industry fully, and thus his work, although valuable, has not removed the need for a more comprehensive analysis and description of the growth of the industry.

This need is perhaps even greater because of the fact that, up to the present, the histories of the machine tool industry in this country, or in fact in any country with the exception of the U.S.A. after 1900,[2] have been written by historians of technology.[3] Although these historians have been very successful in establishing the chronology of machine tool invention,

1 Saul, S.B. 'The Machine Tool Industry in Britain to 1914', Business History, X, 1, Jan. 1960.

2 Wagoner, Harless D. 'The U.S. Machine Tool Industry from 1900 to 1950' (Cambridge, Mass: The M.I.T. Press, 1968)

3 The major works on the technology of machine tools are referred to in footnotes to ch. 2, below, and in the section on technological history in the Bibliography.

and their work will be used extensively below, they have not in general considered the economic implications of the inventions they describe. With the exception of Woodbury, too, they have been concerned more with the process of invention than with that of innovation, and they have largely ignored the speed with which the inventions passed into normal use in the machine shops. As will be argued below in the chapter on international trade in machine tools, this bias has distorted the chronology of the growth of American competition, and thus the basis of the problem of the decline in British competitive efficiency. Furthermore, the concentration by many historians of technology on the design of the tools, or the machining process, has diverted attention from the tasks which the tools were designed to achieve, and thus from the actual results of their application in manufacturing.

The lack of any extended economic history of the British machine tool industry, and the distortions produced by reliance on the writings of historians of technology, thus provides the justification for this history of the industry between 1850 and 1914. The terminal dates of this study have been chosen because both dates mark significant changes in the organisation of the industry. During the early part of the nineteenth century, the machine tool industry in this country developed as an off-shoot of general engineering firms, many of whom made machine tools for their own use. As they developed machine tools to suit their own

purposes, so they gradually began to sell the tools to customers who saw them at work. As the machine tool section of their business grew, so some engineering firms began to specialise more and more in this field, becoming largely makers of machine tools, while other firms were set up specifically for this purpose, one of the first being that of Joseph Whitworth, who in 1833 set up his sign "Joseph Whitworth, Tool Maker from London" over the section of a mill building which he had rented. A specifically machine tool firm established in this period was that of James Nasmyth, who, like Whitworth, was a prolific inventor in this field. By 1850, therefore, it is possible to distinguish a number of firms who depended for much of their custom on the sale of machine tools, and this date is therefore a good starting point for the history of the industry, particularly as the Great Exhibition of 1851 was the first moment at which the skills of the British machine tool-makers became widely known.

The first world war also signalised a change in the organisation of the machine tool industry, the change from the general engineering tradition, in which many different types of machine tools were made to order, to the new, specialised manufacture of machine tools, Machine tool firms, beginning towards the end of the nineteenth century, had restricted the number of products which they were prepared to make, and had tried to achieve pre-eminence in particular fields, but this process was greatly encouraged by the world war and its aftermath, and by the need to meet American competition. 1914 is therefore a convenient date to end this consideration of the industry.

In spite of the need which has been mentioned for an extended history of the machine tool industry in this country, this work cannot claim to describe the growth and development of the machine tool industry in all its aspects. For reasons of lack of space and time it has been necessary to omit certain aspects of the industry. In particular, the enquiry has been restricted largely to the machine tool industry in England, although for technical computing reasons it was not possible to exclude the Scottish industry from the analysis described in Chapter 2. The reason for this omission is that the Scottish industry, which was very much tied to the Scottish shipbuilding industry, exhibits both a different pattern of demand for machine tools, and a concentration on tools of use to shipbuilders which were not made by most English machine tool makers. Although some Scottish makers, foremost among them being Lang's of Johnstone, did achieve wide sales both to England and to other countries, it was felt that to include Scotland as a whole would widen the scope of this study to an unmanageable extent.

The second major omission is that little attention has been paid to the labour force of the machine tool industry. The main reason for this omission is that although it is likely that workers in machine tool factories were, on average, more highly skilled than other engineering workers, this was not enough to distinguish them in any major respect from the bulk of such workers. They were normally members of the Amalgamated Society of Engineers, and the historian of that union does not consider them worthy of any

special treatment. The training and apprenticeship of machine tool workers did not differ from that of other engineering workers, their wage rates were the same, and their conditions of work in other ways appear to have been much the same. It is likely that they were less affected than other engineering workers by the 'machine question', the problem of the introduction of semi-automatic machinery which was one of the major causes of the engineering strike of 1897; on the other hand, many of the employees of machine tool firms, including their highly skilled workers, took part in the strike, so here again they are best considered as part of a larger unit. Particularly in view of the degree of mobility of workers between machine tool and other engineering firms, described in Chapter 3 below, there seems little need in this study to consider the problems of the labour force in detail, and they have therefore largely been omitted.

This study differs from many industrial histories in one major respect, in that the emphasis of the analysis and description is upon the use of quantitative evidence and statistical methods,, rather than upon the use of more traditional sources such as company histories, periodicals, or biographies of the entrepreneurs. In the present state of economic history, such an emphasis seems to require some justification, both in terms of the type of evidence used, and in terms of the methods used to make it yield information of value to the economic historian.

The use of quantitative rather than qualitative evidence to provide the major source for the history of the machine tool industry stems largely from a dissatisfaction with the methods of many previous industrial histories. The emphasis of many of these histories, particularly those of industries which have not attracted great public attention in the shape of statistical enquiries, has been upon writing the history of the industry as an aggregation of the histories of individual firms. The reasons for dissatisfaction with this approach are discussed at more length in Chapter 3 below, but in brief they are that, particularly in an industry such as machine tools which was characterised by the small and often short-lived firm, the information which has survived to the present day is largely drawn from the records of the successful and the surviving firms. If only because they were successful and have survived, these firms must differ in many respects from the bulk of other firms in the industry. Furthermore, even among the firms which have survived, the normal processes of archive destruction mean that only a small selection of the financial records are still available for study. Only Greenwood and Batley among the English machine tool firms, so far as is known, kept their production records, and even their archives are deficient in a number of ways. The majority of firms which possess any records at all have confined their preservation to annual reports and balance sheets, more rarely profit and loss accounts, occasionally sales ledgers, and sometimes ephemera such as catalogues, press cuttings, letter books and similar material, none of which are of much value to an attempt

to write the history of the industry as a whole. As a result, the approach to such a history through company records is subject to rapidly diminishing returns.

Secondly, such an approach can never fill the place of the aggregate production figures, trade figures, and similar guides to the progress of the industry which were not gathered by the governments of the period. Were they available, such sources would form the basis of any study of the industry, and the approach used in this work is therefore to attempt to use other, less perfect sources, to provide the type of aggregate information about the industry which is otherwise lacking. Business records, periodical literature, biographies, and other scattered information on the industry have of course been studied, and ~~is~~ and used throughout, but the main sources of evidence have been threefold.

Firstly the size and structure of the engineering industry as a whole, and the place of the machine tool industry within it, has been explored through the use of the trade directories of the period. Trade directories have been used by economic historians, normally in an attempt to discover the histories of individual firms, and recently they have been used in studies of the economic history of particular areas, in particular of the woollen and worsted industries of the West Riding and of the industries of Kentish London. This work is however, so far as I am aware, the first attempt to use them to study an industry over the whole of Great Britain.

The second major statistical source is used in an attempt to surmount the gap in evidence caused by the failure of the Board of Trade in the period between 1850 and 1914 to classify machine tools separately in the Trade and Navigation Accounts. The source that has been used, the French trade statistics for this period, cannot of course wholly make up for the lack of British statistics, but it does provide exact information about the fortunes of the British machine tool industry in one of its major export markets, and about the growth of American competition in British export markets.

The third, and in many ways most important, statistical source used is paradoxically, the records of an individual firm. While it would of course be ideal if it were possible to study the production of machine tools in a number of firms, the records for a study of this kind do not exist. Since Greenwood and Batley of Leeds have kept so many of their production records for the period from 1856 to the present day, and have generously allowed me full use of them, they have been used to provide a unique view of the day-to-day operations and policy of a single machine tool firm. Greenwood and Batley are unlike many other firms, as is discussed below, but it is better fully to utilise this unique quantitative source, in full awareness of its deficiencies, than to pursue the chimaera of typicality, and in the process to neglect valuable evidence.

The decision to concentrate attention upon these three major statistical sources involved further decisions

as to the method in which they should be used. It would have been possible to have used them simply to provide a background to the analysis, producing from them some descriptive statistics, tables or graphs, and using qualitative materials as the main source of analytical statements. (In fact, the French trade statistics have been largely used in this way, although it is hoped that further use can be made of them in other works.) However, the costs involved in the effective processing of such large statistical sources are so great that simply to use them in a traditional way is to waste a great deal of time, effort and public money. It is also to waste much of their potential to reveal features of the growth of the machine tool industry. For this reason much of this work is taken up with the extended statistical analysis, making use of simple economic and econometric theories, of these quantitative materials. Limitations of time and space have restricted the amount of such analysis, particularly in the wider field of the structure of the engineering industry, and in aspects of the work of Greenwood and Batley, but it is hoped that the aspects of these subjects which have been neglected can be explored in other works.

The detailed characteristics, advantages and deficiencies of these statistical sources are discussed at more length below, as each of them is used, but it is appropriate here to consider in more general terms the problems of their analysis, and some of the lessons which can be drawn from it, possibly for use by others wishing to use similar sources. The major problem which these sources posed was their size. The analysis of

the engineering industry in Chapter 2 involved the recording of four items of data on each of 15,000 punched cards, while the analysis in a more detailed manner of the machine tool industry required the recording of information on 1199 firms in each of 21 years. The French trade statistics provided figures on the import into France of machine tools from six major and a number of minor producing countries over 48 years. Finally the Greenwood and Batley sales and production data allowed the collection of 27 pieces of information on each of approximately 5000 orders for machine tools, a total of approximately 125,000 pieces of data, many of which had to be coded into numerical form.

It was clear from the outset that the use of data sources of such size was impossible without the aid of a computer to produce summary statistics and to facilitate analysis. A major part of the time taken in the preparation of this work was therefore absorbed in the collection, correction and processing of these materials, and in the acquisition of computing and statistical skills to aid in this. Although some of the analysis and production of summary statistics could be carried out with the aid of 'package' programs supplied by computer installations, all the data checking, all the data handling routines to enable the data to be fitted into the requirements of package programs, and in fact the majority of the analysis, had to be carried out with specially written programs, designed to suit the requirements and the deficiencies of

the data being used. One example of these difficulties was the need to write programs to expand abbreviations used to save space in the directories; the name Charles, for instance, was abbreviated to Chas. in a number of cases, and in order to collate and sort the records it was necessary to develop programs to overcome this. The name Chas. had to be replaced by the name Charles in each case, before carrying out the sorting process. In the analysis of the Greenwood and Batley material, complicated internal checks had to be programmed to cope with the mistakes in data recording and punching which inevitably occur with so large a data set.

A subsidiary difficulty of the use of this type of quantitative material of which the Greenwood and Batley data is an example is the quantity of missing data. This is a common problem of econometric investigation, and of course of historical investigation generally, but it poses considerable difficulties, particularly in the use of package programs, which generally allow for the exclusion of records only if one particular condition is not satisfied; they are not suitable therefore for the analysis where the decision on whether or not to include a record is dependent on whether two or three conditions are satisfied. In many cases, too, package programs designed originally for analysis of experimental data make no allowance for missing data, and are therefore entirely unsuitable.

Until more suitable computing routines are developed, therefore, it is clear that the economic historian

wishing to make extensive use of quantitative material will have to become adept at computer programming and data processing techniques. Unfortunately, the acquisition of such skills is an expensive and time consuming process, not only for the researcher but for his university or grant-providing body. This applies even in the rare cases in which it is possible to employ professional programmers, since although this process may save the time of the researcher it may well, unless the researcher is entirely clear as to his needs, be wasting the much more valuable time of the programmer. The experience of the work required to produce the results which are described and analysed below therefore suggests that, in the interest of economy of effort and expenditure, it will be necessary to keep a close watch on the returns to such effort and expenditure. It is secondly clear that if such projects become more common, then considerable savings could be achieved by the provision of more comprehensive assistance to researchers, in the form of training programs for non-scientific researchers and in the provision of technical assistants to carry out the semi-automatic recording, coding and punching tasks involved in preparing data for analysis. Such provision is of course normally made in scientific research, but it will have to be extended to the arts disciplines if full and economic use is to be made of the type of materials which are analysed below.

The purpose of the fore-going discussion has been to refer to some of the difficulties encountered in the analysis of the machine tool industry through quantitative materials. These difficulties have to some extent shaped

the succeeding chapters, in particular in the omissions that have been made, and it is therefore useful to describe at this point the context of these chapters, and the relationship which they bear to each other.

One of the difficulties associated with the description of the history of an industry is the need to explain, in an intelligible fashion, the technology of that industry and its development. The next chapter therefore describes, from the writings of historians of technology, the characteristics of the major types of machine tools and the chronology of their introduction. This chapter is essentially a preliminary to the whole work, and the first analytical chapter is that which follows. In this, the machine tool industry is placed within the wider context of the engineering industries, and secondly the growth and fluctuations in the industry are described. This is supplemented in chapter 3 by a description of the machine tool entrepreneurs, of the major firms, and of other characteristics of the growth of the industry, using largely non-quantitative sources. In chapter 4, the industry is considered as one of a number of competing producers in the world market, and its export and import-saving performance is analysed, in particular in relation to that of the American industry. In chapters 5 and 6 aggregative analysis of the preceding chapters is supplemented by the detailed investigation of the sales and production records of Greenwood and Batley, and in particular of the relations of the firm with various groups of customers, and, in chapter6, on the question of productivity change.

Finally the concluding chapter summarises the results of the analysis, and the conclusions which can be drawn from it as to the place of the machine tool industry in the economic history of the period.

CHAPTER I

THE TECHNICAL HISTORY OF MACHINE TOOLS, 1850-1914.

This thesis is concerned with the economic history of the machine tool industry between 1850 and 1914, but in order to appreciate the technical forces which shaped the development of that industry, and to understand the references which are made to different types of machine tools and to their functions, it is necessary to begin by defining and describing the major types of machine tools then made, and to continue by describing the history of machine tool technology during the period.

No attempt has been made, in this chapter, to go beyond the published works of historians of technology specialising in machine tools, and the history of tools themselves is thus drawn entirely from these authorities, rather than directly from the records of the machine tool industry. The use of material collected and published by historians of machine tool technology is however not entirely straightforward, since the major interest of the majority of such writers is in the processes of invention, while to an economic historian the main interest of technical history lies in the process of innovation. In this chapter therefore, where some information is available, an attempt is made to look at the economic significance of the inventions whose chronology and provenance has been established by the historians of technology; unfortunately in most cases this is an impossible task because of the paucity of records.

Definition and description of machine tools.

The best of many definitions of machine tools is that given by W. Steeds in his "History of Machine Tools, 1700-1910", that "as briefly as possible," machine tools are :

> "contrivances in which a cutting tool is used to bring a piece of metal to the shape, size and degree of finish required by the operator and which to some degree reduce the manipulative skill and physical strength he needs to achieve his object. This excludes such things as rolling-mills, coining presses, and sheet-metal working tools, in which changes of shape and size are produced by means of plastic flow in the material being formed. It is also taken to exclude such things as portable electric drills, but to admit machine tools such as simple lathes in which the tool is held and guided by the operator and in which a high degree of skill may be required of him. It also excludes all wood-working machines."[1]

The major types of machine tools which fall within this definition are lathes, drilling machines, boring machines, planing machines, shaping machines, slotting machines, milling machines, grinding machines, shearing machines and sawing machines, some pressing machines which have a cutting action. Unfortunately, these are not discrete categories, since many machine tools combine in one machine operations which can be carried out separately by other machines. The names given to certain machines have also varied over time, and between countries.

1 Steeds, W. History of Machine Tools, 1700-1910 (Oxford, 1969), p. xix.
Much of the material in this chapter is taken from this comprehensive work.

As Steeds points out :

> "...the machine now commonly called a 'vertical lathe' has, in the past, been called a 'circular planer', a 'turning and boring mill', and even a 'horizontal lathe', — the last because its work table was horizontal. The term 'capstan lathe' has a fairly definite meaning in Britain but is not used in America, where 'screw machine' is used to describe the same thing." [2]

As will be apparent from Steeds' example, the basic name of a machine tool is normally modified by some adjective describing the alignment of one or other part, (horizontal, vertical, straight), the capacity of the machine tool to perform different jobs (plain, universal), the method by which it performs them (radial, multiple), or even the final product (screwcutting, cutter grinding). All these modifications make it extremely difficult to describe even the most common machine tools, so that attention will be confined mainly to description of the basic types, even if these were in fact rarely if ever made without some modification.

The lathe performs the metal-cutting operation known as turning. In the basic lathe the work-piece is rotated between two supports, known as centres, while the cutting tool is held against it. The cutting tool is thus static, while the work-piece revolves, although the tool may be moved from one end to the other of the work-piece, to allow cuts to be taken at different places. Many types of lathe dispense with the two centres, the work-piece being clamped to a face-plate, and the cutting tool being brought into operation against the side or edge of the work-piece,

2 Steeds, W. op.cit. p. vii.

which still revolves. In the capstan turret lathe a number of different cutting tools are clamped into a tool-holder, in pre-set positions, and are then rotated or indexed to allow them to cut the work-piece one after the other. This allows a sequence of operations to be carried out without the need to remove and replace different cutting tools, and was an important aid to speeding up turning operations.

The drilling machine holds a drill or other end-cutting tool in a spindle which is rotated and fed towards the work-piece. Drilling machines thus operate on a static work-piece, while the cutting tool revolves. Boring machines operate on the same principle, but the cutting tool is differently shaped, to allow it to cut a hole of a wider radius than could be accomplished with a drill bit. In some boring machines, however, particularly those made early in the nineteenth century, the boring tool was supported on a bar placed in a hole already roughly cut or cast.

In the planing machine the cutting tool is again held static, while the work-piece, clamped on the work-table, is fed past it with a reciprocating motion. The tool may be moved transversely between each motion of the work-table, thus allowing the whole of the work-piece to be machined. Normally the work-table is horizontal, the cutting tool being suspended above it on a bar held between two standards. Various modifications of planing machines allow the cut to be taken in both directions, or provide for a quick-return motion of the work-table, thus reducing the time wasted in returning to the beginning of the stroke.

The shaping machine, like the planing machine, is used to produce flat surfaces. In the shaping machine, however, the work-piece is static, while a cutting tool attached to a ram is fed across it in a straight line with a reciprocating motion. The work-piece is fed transversely on each return stroke, the ram head being hinged to allow the cutting tool to pass over the work-piece on the return stroke. The slotting machine is essentially a version of the shaping machine, but the vertical rather than the horizontal face of the work-piece is machined.

The basic feature of the many types of milling machines is that the cutting tool is a rotary cutter with multiple teeth, unlike the single-edged or double-edged cutters used in all the machine tools previously mentioned. Milling machines can however, by the use of different shapes of rotary cutters mounted in different positions with respect to the work-piece, perform many of the operations of the other machine tools, and are one of the most versatile of machine tools.

The grinding machine employs an abrasive wheel or wheels to remove metal through the contact with the work-piece of "thousands of points simultaneously and millions of points continually".[3] The cutting tool is thus entirely unlike the cutting tools used in other machine tools. In other respects, however, in the

3 Woodbury, R.S. History of the Grinding Machine (Cambridge, Mass., 1959), p.8.

methods by which the cutting tool is applied to the work-piece, many grinding machines employ virtually the same mechanisms as those used in other tools; early grinding machines in fact consisted of grinding wheels fixed to the tool-holder of a lathe. In some grinding machines the work-piece revolves while the tool is fixed, but in most the work-piece is held steady while the tool revolves; in the cylindrical grinder both the work-piece and the cutting wheels revolve.

The other machine tools are relatively familiar. Shearing machines operate with a guillotine motion to cut metal, partially through the force of their own weight. Sawing machines use multiple cutters arranged on a metal band which is reciprocated across the work-piece. Pressing machines, (other than those which utilise the plastic properties of metal to form a shape) again cut with a guillotine motion.

One extremely important machine tool has not so far been mentioned, since it is distinguished from those already considered rather by its function than by its method of cutting. This is the gear-cutting machine, which almost always uses the cutting methods of milling, shaping, or slotting machine. As Woodbury says, however, "Probably none of the machine tools has called for more knowledge of geometry and more ingenuity of design to solve its unique problems."[4] Its development, inmany different forms, allowed the solution of one of the major problems of mechanisati ..,

4 Woodbury, R.S. History of the Gear-Cutting Machine (Cambridge, Mass., 1958), p.3.

that of regulating the speeds and ensuring accuracy of control of machinery, and it is thus normally considered as a separate type of machine tool of considerable importance.

The technical development of machine tools, 1850-1914.

The majority of the tools which have just been described were invented before 1850, several of them, like the lathe, drilling machine and grinding machine in prehistoric times. The industrial application of those tools to the machining of metal in large quantities was however largely achieved in the second half of the eighteenth and the first half of the nineteenth centuries, in response to the demand for accurate machining created by the industrial revolution. The basic form of the major types of machine tool (with the exception of the milling machine, the turret or capstan lathe, and the various gear-cutting machines, which were all effectively developed after 1850), thus did not greatly change between 1850 and 1914, and changes in them were confined to relatively minor alterations in size, capacity and method of operation. Although these changes were minor by comparison with the initial development of the machine tools, they made a very considerable difference to the productive potential of machine tools; discussion of them is however complicated by the fact that they were unspectacular and that the changes and improvements which they produced were obtained gradually, often as the result of hundreds of minor modifications.

Apart from these modifications in the tools themselves, the period from 1850 to 1914 was one in which several

major changes occurred in cutting tools, and in the methods by which the machine tools were powered. These modifications affected all types of machine tools, and they will therefore be considered first, before the detailed changes in the majority of machine tools, and the development of other types of tool are described.

Cutting tools.

As Rolt points out:

> "it is obvious that the efficiency of any metal-cutting machine depends absolutely upon the ability of the actual cutting tool to do the work required of it. Indeed, it would be true to say that the machine is designed round the cutting tool since its proportions, its feeds and speeds are necessarily determined by the tool's cutting ability." 5

Before the development of special tool steels and the use of metals other than steel in the second half of the nineteenth century, metal working was seriously hampered by the inadequacies of carbon steel cutting tools. Although carbon steel was used successfully in the early machine tools during the industrial revolution, tools made of it required constant sharpening and hardening, since carbon steel was too soft to retain a cutting edge for a long period, particularly as cutting speeds were increased. There was no scientific knowledge of the properties of steel, and none concerning methods of sharpening, so that each user had to develop his own methods. A description of American engineering in the 1860s gives methods for initially hardening, and for rehardening, cutting tools. To harden the tool, the engineer dipped the tool in a

5 Rolt, L.T.C. Tools for the Job (London, 1965), p.63.

mixture of 2 lbs. pitch, 1 lb. whale-oil, and ½ lb. tallow, and secondly in a mixture of 1 lb. of pulverised sal-ammoniac, ½ lb. tartaric acid, 4 qts. water, and 1 pt. red wine. To reharden the tool for daily use it was dipped in a further mixture of 1 lb. tallow, ½ lb. sal-ammoniac, ½ lb. prussiate of potash, ½ lb. black resin, 1 oz. pepper, and 1 oz. shaving powder.[6]

Both carbon steel itself, and these various methods of hardening it for use in cutting tools, had evolved without any scientific investigation, virtually by accident. During the second half of the nineteenth century, however, numerous scientific experiments did result in very considerable technical improvements. In 1860 the first improved tool steel, with the extremely important property that it was self-hardening, was produced by Robert Hushet. This tool steel made it possible both to increase the speed of operation of machine tools, and to machine the newly introduced manganese steel produced by the Bessemer and Siemens-Martin processes. The major experiments in this field were however carried out in the United States by Frederick W. Taylor, working with Maunsel White of the Bethlehem Steelworks. Taylor experimented both with different methods of using existing tool steels, and with the development of new materials, and over a period of twenty years greatly altered engineering practice in both these directions. Taylor and White replaced the manganese in Hushet steel with chromium, increased the tungsten content, and finally added silicon.

6 Weissenborn, G. American Engineering (New York, 1861) p.25.

This new alloy allowed the cutting speed of the tools to be increased from under 30 feet per minute to approximately 80-90 feet per minute. Taylor and White concluded their experiments by adding vanadium to the alloy, further increasing the strength of the tools.[7]

The result of these improvements was greatly to increase the speed of feed of the cutting tool, unfortunately far beyond the strength of the existing machine tools, which fell to pieces when run at the new speeds. After the introduction of the new high-speed tool steels, as they were called, from 1900 onwards, all machine tools were therefore gradually redesigned to cope with the higher speeds, and thus the greater strength and stability which was required. This process of redesigning all the machine tools then in existence, and of producing new types of tools, does not seem however to have been as rapid as might have been expected, considering the undoubted cost advantages of the new tools. Rolt recalls that when he served part of his apprenticeship in a British engineering shop in 1929 it still used carbon steel tools on a lathe, having to take them to be tempered by the shop toolsmith.[8] He suggests that since, to take full advantage of the new high steels would involve a machine tool user in scrapping his entire plant and buying newly designed machine tools, most users preferred simply to buy the new machine tools as their old tools wore out. It is not clear how this affected the machine tool industry itself; the

7 The information in this paragraph is taken from Rolt, L.T.C., op.cit., pp. 199-200.

8 Rolt, L.T.C., op.cit., p. 215.

design and retooling costs involved in introducing the new generation of machine tools would have been very heavy, especially if the introduction of new tools did not stimulate increased purchasing by users, but there is very little sign that British machine tool makers were concerned about this, at least before 1914. It seems likely that the introduction of the new machine tools was, in Britain at least, a very gradual process, which did not have a great impact on the industry, largely because of the inertia of many potential customers.

Driving methods.

Traditionally machine tools, like other machinery, were driven from a central steam engine in each shop, power being transmitted to individual machines through overhead belting. Changes in speed were achieved by the use of different sizes of pulley-wheels over which the belt, made of leather or canvas, ran. This method had serious deficiencies; the large number of belts required made the shop both dark and dangerous, changes in speed could be made only by changing to other wheels, in a series of steps, the whole shop was dependent upon the operation of one steam engine, which at least in the early part of the century often broke down.

Although, as Rolt says, shops of this kind could still be found in Britain in 1930,[9] there were, during the late nineteenth century, a number of important changes in the methods by which machine tools were driven. Change-gears, with which the speed of a machine

9 Rolt, L.T.C., op.cit., p.215.

tool could be varied without stopping the machine, were introduced. The single-pulley belt drive, working with a geared headstock, replaced the system of multiple pulleys in the driving of lathes and other light machine tools. This made it possible to move towards the provision of a single motor, often driven by electricity, for each machine tool, eliminating the use of overhead shafting and pulleys.[10]

It is very difficult to assess the effects of the introduction of these new methods, which Steeds dates to the period after 1890. Although these methods affected the design of machine tools, the changes which they made necessary were less spectacular than those produced by the high-speed tool steels. It was also necessary for the machine tool makers to continue to make tools driven by a variety of methods, to suit the power available to their customers. Thus although in the early years of the twentieth century many machine tool makers introduced machine tools incorporating these improvements, as Steeds shows, it is impossible to tell what proportion of tools sold incorporated the new methods or, as with high-speed tools, what the costs of their introduction were.

The changes in tools and in driving methods discussed briefly above were applicable to a wide variety of machine tools. There were also improvements in each type of tool, and new types of machine tools were invented. In the remainder of this chapter, therefore, the more

10 Steeds, W., op.cit., pp. 118-119.

important of these changes will be described.[11]

Lathes.

Woodbury concludes his survey of the development of the lathe to 1850 by stating that by that date ".. the lathe had developed into an industrial machine tool of precision and high capacity." [12] The main changes in the lathe during the middle of the nineteenth century were directed towards increasing the size of this machine tool, and widening the range of operations which it should undertake. Lathes were produced with two tool rests, with two headstocks and with various other modifications. But the major development was that of the turret lathe, which Steeds describes as revolutionising machine shop practice in lathe work.[13] There is considerable controversy about the exact details of the invention of the turret lathe, but it almost certainly originated in the United States between 1840 and 1850, and was probably first employed in the manufacture of small arms.

As Steeds suggests, the major development of the turret lathe, both in modification of its design and in its commercial introduction, came between 1860 and 1890. Essentially, while the traditional lathe was improved

11 Unless otherwise attributed, information on the technical development of machine tools in the succeeding paragraphs is taken from Steeds, W., op.cit.

12 Woodbury, R.S. History of the Lathe to 1850 (Cambridge, Mass., 1961), p. 117.

13 Steeds, W., op.cit., p. 55.

in detail and increased in size, the turret lathe was developed as a new type of machine tool, fulfilling distinct functions particularly in mass production of simple components. A further development of this type was the automatic screw machine, developed in the United States and Germany, and introduced into Britain by Greenwood and Batley in the 1880s. This allowed the virtually automatic machining of bar stock which was fed through the chuck of the lathe past a turret containing a number of tools which were brought into position through the use of a cam-shaft. Many British machine tool makers, and their customers, continued however to view the turret as simply a place to store a number of cutting tools, which were swung into position by the operator, rather than as a move to automatic operation as in the screw machine. This situation gradually changed up to 1914, and was combined with the improvement of the traditional types of lathes, and with the development of multi-spindle automatic lathes.

The introduction of these new types of lathes, and the movement which was implied in them towards fully automatic machining, was one of the major sources of dispute between engineering employers and the Amalgamated Society of Engineers which culminated in the engineering strike of 1896. The 'machine question' as it was called, essentially concerned the replacement of skilled workers operating single machines by the new semi-automatic machines which could be operated by semi-skilled operatives under the over-sight of a skilled toolsetter. It is unfortunately difficult to know how many of these new

machines were imported from the United States. It seems likely that, as with the other changes that have been mentioned, their introduction was gradual and was conditioned by the slow speed of deterioration of the older types of lathes, although the fear of unemployment that these new machines aroused among engineering workers was certainly very real.[14]

Boring and drilling machines.

There were no major developments in boring machines between 1850 and 1914, but particularly after 1890 a number of machine tools were introduced which combined boring with other functions of machine tools. Lathes had previously been used for boring, and turning, boring and drilling was combined in one machine tool in 1892. Multi-spindle boring machines were also developed to be used in mass production.

The major change in the drilling machine in the early part of the period was the introduction and development of the radial drilling machine. In the early types of drilling machines the drill head was fixed, only vertical motion being possible, so that the work-piece had to be repositioned for each hole to be drilled. With the radial drill both vertical and horizontal, and eventually angular, movement of the drill head was possible, the head being attached to an arm from a column or from the wall, so that the work-piece could remain clamped in one place while the drill moved above it. The usefulness of the drilling machine was also

14 Jeffreys, J.B., The Story of the Engineers, (London, 1946) ch. VI. See also below, Chapter 5.

greatly increased by the introduction of twist drills after 1861, when Joseph R. Brown invented the universal milling machine to make them. Previously the drill had been simply a pointed piece of metal, with no cutting edge, and the introduction of the double-edged twist drill greatly increased the capacity of the drilling machine.

After the introduction of the twist drill, which was at first fiercely resisted particularly in Britain, few changes were made in the design of drilling machines before 1914, although there was considerable development, as with boring machines, of multiple spindle machines to meet the needs of mass production.

Planing machines.

There were no major changes in the design of planing machines between 1850 and 1914, apart from the introduction, early in the period, of the wall or side planer; these tools were particularly useful in machining large and heavy work-pieces, since the work-piece is static, being clamped on the floor while the cutting tool travels along it, supported on ways built into the side of the building. Otherwise there were improvements in the reversing mechanism, always a source of difficulty in design, but in general the modifications in design were much as with the other machine tools, increasing the size of the tools and making them more versatile and easier to operate.

Slotting machines.

Slotting machines were invented in the 1830s, and remained almost unchanged throughout the period to 1914, although there were some changes in size, and experiments in combining them with drilling machines.

Shaping machines.

Shaping machines, which date from about the same period as slotting machines, also underwent virtually no significant changes in design before 1914.

Milling machines.[15]

The milling machine, on the other hand, was largely developed during the period from 1850 to 1914, although some types of milling machine were in use before 1350 in the United States, and Nasmyth is said to have invented a form of milling machine in England. Before 1861 the major type in use in the United States, although it was also exported, was the Lincoln miller, described by Woodbury as the first production milling machine. In 1861, however, Joseph R. Brown invented the universal milling machine, which although it was designed initially for the manufacture of twist drills, was soon used for a variety of tasks. This invention was combined with improvements in the design and manufacture of milling cutters, which had been one of the major difficulties of the earlier machines. Numerous modifications of the basic milling machine were introduced during the rest of the period, and as Steeds states :

15 Much of the information in this section is taken from Woodbury, R.S., History of the Milling Machine (Cambridge Mass., 1960)

> "the milling machine developed from a machine that was built by firms for their own use, usually for a particular type of job, until it became of equal or greater importance than the planing, slotting and shaping machines and was being built for sale by numerous firms in most countries that had any machine tool industry."[16]

It is again difficult to estimate the direct impact of the milling machine on British industry in general or the machine tool industry in particular. The impact of the twist drills which it made cheaply and efficiently was considerable, after some delay, and milling machines themselves were certainly introduced quickly into England, particularly into arms factories. They were among American tools bought when the Enfield Small Arms Factory was equipped, and Greenwood and Batley were making and selling them to arms makers from the 1860s onwards. Their use must have improved the productivity of industries using them, since they not only made machining easier and quicker but also replaced a number of other machine tools, but it is impossible unfortunately to quantify this impact in any way.

Gear-cutting machines.

The development of gear-cutting machines largely took place during the period from 1850 to 1914, although clock-makers had used wheel-cutting and dividing engines for centuries. The major changes were that the size of the machines was greatly increased, so that industrial gearing could be produced, that gear-cutting machines were designed to work automatically, simply

16 Steeds, W., op.cit., p. 102.

following a pre-cut pattern, and finally and probably most importantly, that machines were designed to generate gear patterns, rather than copying them. Together with these developments was a considerable amount of investigation into the capacities and uses of different shapes of gears, and a considerable increase in accuracy.

Grinding machines.

The last major type of machine tool, which was largely developed as a production tool after 1850, is the grinding machine. The major developments came between 1860 and 1890, cylindrical and surface grinders being developed simultaneously, and both were facilitated by the development of new types of abrasive wheels. One of the major difficulties with the early types of grinding machines was the poor quality of the abrasive wheel, particularly since the early wheels had a tendency to burst when being operated. The first really successful artificial grinding wheel was developed in 1877, and, as Rolt says, this made precision grinding possible.[17] The precision grinding machine was developed in the United States by Brown and Sharpe and numerous modifications and new types of grinding machines were introduced, together with investigations of the optimum speeds and methods of working by Charles H. Norton, much on the model of Frederick W. Taylor's investigations of the cutting tools. New materials were developed for the abrasive wheel, notably silicon carbide and alundum, and Norton's

17 Rolt, L.T.C., op.cit., p. 179.

work allowed the specification of correct speeds and methods of feed, and greatly increased the accuracy and capacity of grinding machines. Norton also was responsible for the major change in usage of grinding machines, from machines for finishing work started on other machine tools to machines which would carry out the whole process from the rough casting to the finished smooth stage.

This survey of the technical development of machine tools between 1850 and 1914 has been necessarily short and in many ways incomplete. It is so, partly because it is designed as an introduction and an explanation of the various terms which have to be used in a study of the machine tool industry, and partly because the information on the process of innovation is so inadequate. The books of Woodbury, Steeds, Roe and Rolt, which have been used in writing this chapter, concentrate very largely on the process of invention, although both Woodbury and Rolt show themselves to be aware of the importance of assessing the actual use of the inventions they describe. Neither can in fact provide much information of this kind, and without a careful study of catalogues, technical publications and the sales records of many firms, it is difficult to say where the information for such a study could in fact be found. Furthermore, even in the case of Greenwood and Batley, where catalogues, photographs of the machines, and sales records, are available, no very definite conclusions can be drawn, because of the multiplicity of machine tools which were made, about 500 differently named tools between 1856 and 1900.

The major conclusions which can however be drawn from the short survey of technical development given above is that, for the majority of the major types of machine tool, change during the period 1850 to 1914 was essentially a process of a series of minor adaptations and improvements, which over the period as a whole markedly increased the capabilities and the ease of operation of the tools, but did not change their basic forms, expept through the introduction of different sizes of tools. New types were introduced, notably milling, grinding and gear-cutting machines, but with these also, once the initial invention was made, the basic design of the machine tool changed little before 1914. Increases in cutting speeds, and much greater accuracy and precision, were the result of improvements in tool steels and in driving mechanisms, and these were applied throughout the field, but their adoption was, at least in Britain, slow and steady rather than spectacular.

CHAPTER 2

THE STRUCTURE OF THE MACHINE TOOL INDUSTRY.

In the first half of the nineteenth century it is impossible to distinguish a group of firms which can be called 'the machine tool industry'. By 1914 such a group of firms existed, had its own trade association,[1] and was clearly distinguishable in the great complex of the engineering industries. This chapter will be concerned to describe, and to attempt to explain, this transition.

A full treatment of the development of the engineering industries as a whole, which would be a desirable prelude to a discussion of the development of one of its component parts, the machine tool industry, is beyond the scope of this work. As Professor Saul has pointed out, we need detailed studies of the various engineering industries before we can make detailed statements about the development of the sector as a whole, and we do not have such detailed studies for most of the component industries.[2] Nevertheless, it is necessary to consider, at least in outline, the development of the engineering industries as a whole, because of the light which the

1 The Machine Tool Trades Association was formed in 1911. Its main function at that time was the organisation of of the Machine Tool Exhibition.

2 Saul, S.B. "The Market and the Development of the Mechanical Engineering Industries in Britain, 1860-1914", Econ. H.R., 2nd series, Vol. XX, 1, April 1967, p. 111.

general characteristics of those industries can throw on the singlesector of machine tool production. Such a consideration is made doubly necessary by the unique place of machine tool production within the engineering industries, as both a branch of those industries and an essential supplier of the machinery used by the other branches. Developments in engineering, and the structure of the engineering industries, had, for this reason, a much greater effect on the machine tool industry than on their other constituent branches; it is concomitantly more difficult to distinguish between endogenous change within the machine tool industry, and change which is induced by developments outside, in the industries to which machine tools were sold.

It is generally accepted that the evolution of the engineering industries in Britain during and after the industrial revolution is one of change from unspecialised jobbing metalworking to highly specialised engineering in which firms made one, or at least a small number, of types of machine, often in only a small range of sizes. Professor Saul has described the process as far as 1870 :

> "During the third and fourth decades of the century the industry had begun to develop away from the earlier pattern, whereby all manner of metal jobbing was undertaken, into more specialised organisations. Complete specialisation was still rare, but makers of locomotives, textile machinery and heavy machine tools came closest to it, though there was little or no concentration within a particular field of activity." 3

The trend towards specialisation continued up to the first

3 Saul, S.B. "The Engineering Industry" in "The Development of British Industry and Foreign Competition 1875-1914." ed. D. H. Aldcroft (London, 1968), p. 186.

war and beyond, urged on by those who saw the lack of it as one of the factors responsible for the declining competitive position of the British engineering industry. Specialisation was greater in some industries than in others, and the size of engineering firms also varied greatly, from the giant railway workshops to the small businesses of the Birmingham hardware districts and the scattered makers of agricultural machinery, many of them not far removed from blacksmiths. The trend towards 'modern' specialised units of production was, however clear in many fields, however slow the progress towards it.[4]

This description has at least the attractions of simplicity, but it needs further examination. It says very little about the actual process by which the industry was transformed. It cannot tell us whether the process was one by which old firms gradually narrowed their range of products, or whether they were superseded and forced out by new firms entering already specialised. It cannot tell us whether the size of the industry changed as its structure was changing, and how these developments interacted. It cannot tell us what kind of specialisation was achieved, whether it was specialisation in the production of

4 History of Ministry of Munitions, vol. VIII, part III, p.38. P.L. Payne, "The Emergence of the Large Scale Company in Great Britain, 1870-1914" (Econ.H.R. XX, 3, Dec. 1967, p. 524) attributes specialisation generally in British industry to product differentiation designed to achieve oligopolistic control, and implies that there was a growing number of firms adopting the strategy.

one commodity, or in the production of a range of technically similar products, or in the production of a range of goods for one consumer industry, or some sub-division of one of these.

These questions must be answered, however imperfectly, before the place of the machine tool industry in the whole process, and the structure of that industry, can be discussed. It is necessary to know whether the changes in machine tool production, which are to be studied in detail, were typical of the industry as a whole, or whether its progress was entirely heterodox, in relation to all these questions.

It is difficult to answer these questions. Traditionally, the history of British industries has been approached as if it were a type of aggregated business history; one might add up the histories of all the firms, and then one would have the history of the industry. This approach has been forced on economic historians by the nature of the available data, which has normally been the records of individual firms; the findings from these have been combined with scanty aggregate production and trade statistics, and the whole seasoned with the qualitative comments of contemporary observers. A great deal of illumination has been gained by such methods, but they are of limited value unless they can be complete and, can cover all firms in the industry. Furthermore, the data available inevitably refers to the leading firms, to the firms whose records have survived, to the firms which attracted press attention, to the firms who made important technical progress.

Traditional methods cannot illuminate the submerged section of the industry, technically less progressive, with smaller workshops, less efficient book-keepers and less enterprising managers; yet these firms may have been responsible for the bulk of production. As an illustration of the difficulties of the traditional method, which Saul himself is the first to admit, one can cite Professor Saul's work on the machine tool industry; he identified 129 firms "in the four main areas of machine tool production" in 1913, but was unable to discover even the minimum of information about 69 of them.[5] He was able to obtain figures of output for only 10 firms, responsible between them for only 29% of the total output of the industry as it was recorded in the 1907 Census of Production.[6] It is possible that in some of the engineering industries which had smaller number of units, for instance locomotive production, it may be possible to achieve a wider coverage, but it is likely that Professor Saul's experience is not untypical; it has also to be remembered that securing the necessary information becomes progressively more difficult as the enquiry is pushed back into the nineteenth century.

5 Saul S.B., "The Machine Tool Industry in Britain to 1914" Business History, vol. X, 1, January 1968, p. 42.

6 The firms included were Archdale, Butler, Asquith, Parkinson, Herbert, Lang, Craven, Hard, Richards, and Greenwood and Batley. Details of output for all except the last were kindly provided by Professor Saul, and were obtained by him from the records of the firms. For details of Greenwood and Batley output see ch. 6 The total output of these firms was £858,000 in 1907 (of which Herbert provided £324,000), and the Census of Production showed total output of the industry as £2,936,000. (Final report of the Census of Production,1907 P.P. 1912-13, cix, 1. p. 126.)

In order to answer the questions which have been posed about the developing structure of the engineering industries, it is necessary to adopt different methods, since the traditional methods help us to understand only the probably untypical experience of a few firms. In the rest of this discussion of the structure of the engineering industries, therefore, an attempt will be made to describe the industries through material gathered from contemporary trade directories. The data from these sources will be used to discuss the accepted view, stated in summary above, of the changing structure of the engineering industry during the period up to 1914.

The difficulties associated with the use of directory material in elucidating the development of an industry are as numerous, and as severe, as those associated with the more traditional methods which have been described, and a discussion of these difficulties must precede the use of the data. The directories used in this study were those produced by Kelly and Co., called the (Post Office) Directory of Merchants, Manufacturers and Traders. They were compiled by agents, employed by the publishers, each of whom covered a particular area of the country. The agents were directed to get in touch with every business concern in their area, to inform them that each firm was entitled to a free entry in the directory under every heading with which it was concerned, and to collect this information on products or types of business for inclusion in the directory. This procedure was repeated every time the directory was published, at first every

two or three years, but by the 1890s annually. The cost of the publication was covered by sales and by advertisements; firms could pay for advertising space in the directory, or could pay for the printing of their entry in a heavier or larger type than the normal entries, or could pay for the insertion with their entry of some extended description or praise of their product.[7]

The accuracy of information gathered from these directories is directly dependent on the accuracy with which they were compiled. It can plausibly be argued that it was in the interests of all concerned to ensure that the directory was as comprehensive as possible. The publishers had this aim because of their wish to ensure that the directory was as useful as possible, and thus a more attractive purchase. Each individual firm had an interest in seeing that it was included, particularly if this competitors were, and an interest in seeing that it was listed under as many headings as it had products. This raises the question of whether the directory might be over-comprehensive, might include firms under headings in which they were not really competent. It is again true that the publishers would have an interest in avoiding such exaggerations, which would reduce the attractions of the directory. Secondly it can be argued that no firm would seek business in a field in which it was totally incompetent, since the

7 This information on the methods used by the compilers of Kelly's Directories was given to me by Mr.G. Barkway, Manager of the U.K. Division of Kelly's Directory of Merchants and Manufacturers.

costs of undertaking stray orders in such fields would be very high. It is possible, in other words, that firms may be listed under headings in which they were not normally employed, but they would be at least potential producers in that field, while the interests of the publishers would exert pressure on them not to exaggerate their skills. On these grounds, therefore, it seems reasonable to treat the directories as reasonably accurate evidence; it will be shown later that the information from them on the machine tool trade is consistent with other evidence about the size of the industry.[8]

Given therefore that the directories are an accurate source of information it has to be asked whether they can provide answers to the questions which are to be asked. The information is incomplete in two important respects. No information is given on the size of the firms; each is given one entry however large or small it is. Secondly the classifications which are used by the directory compilers are in terms of industries; a firm will be listed as a maker of machine tools, not as a maker of heavy or light, cheap or expensive tools, or under particular tools. Thus the directories can give no information on whether a firm specialised within an industrial group, as we know from qualitative information many were increasingly doing. These are serious defects, but they do not remove entirely the usefulness of this evidence. The defects are in different directions to those of the traditional methods, so that

8 See below pp. 66-100

to use traditional methods together with the directory material may produce a net gain, and the material will therefore be so used.

The use of the directories does have a further drawback, and that is that partly because of the size of the numbers of firms in the industries, and partly because each firm might be listed under a number of different headings, the bulk of the material is very great, and processing can only be undertaken with the use of a computer. Even so, the bulk was so great that only three years could be studied; 1907 was chosen because Census of Production figures on output are available for that year, and 1892 and 1877 were chosen to span the period over which the directories were published, at 15 year intervals. The list of industries was chosen to correspond roughly with the Census of Production definition of the engineering industries. A list of the industries, and the methods used in recording and processing the material, is given in appendix 2, 1. In discussing the material the following definitions will be used :-

entry - the individual mention of one firm under one heading.

firm - the unit of organisation, one firm having one or more entries, corresponding to the number of products made.

product - the type of engineering product produced, as defined by the directory compilers, and listed in appendix 2, 1.

product group - the total set of entries concerned in the manufacture of a product.

For example : The firm of Greenwood and Batley had an entry as a manufacturer of machine tools, its product. It therefore formed part of the product group making machine tools.

engineering industries - the total set of product groups.

The evidence from the directories as to the total size of the engineering industries is as follows :

In 1877	1721 firms had 2509 entries,	divided among 36 product groups.
In 1892	3755 firms had 5773 entries,	divided among 42 product groups.
In 1907	3429 firms had 5104 entries,	divided among 34 product groups.

TABLE 2, 1. Size of engineering industries.

It is apparent that the engineering industries became [illegible] in terms of number of firms, during the period up to 1892, falling back slightly to 1907. This is entirely consistent with qualitative evidence; this was as a whole a period in which particularly the light engineering industries were expanding greatly, with the rise of the new trades such as cycle manufacture, sewing machines, and the other Midland industries. As these were new trades, and many of them were situated in new engineering areas of the country, it is reasonable that much of the expansion should have come through the

formation of new firms, rather than by the old engineering firms turning to new products. In fact only 13.2% of the firms listed in 1892 had survived from 1877, and only 30.9% of the firms listed in 1907 had appeared in either 1892 or 1877 (or both). It is also apparent that the new firms made fewer products, on average, than those who had survived from earlier years. In 1892 the average number of products made by the new firms was 1.31, and by the survivors 2.30; the comparable figures for 1907 were 1.31 and 1.89. The expansion of the agricultural machinery industry in particular, which tended to consist of small, scattered firms, also contributed to the expansion of the total number of firms. (It is possible that deficiencies in compilation were responsible for the low number of firms shown in 1877; the figures for the machine tool industry for that year are however consistent with those for earlier and later years.)

The normally accepted hypothesis about this period is that it was one in which the engineering industry showed signs of increasing specialisation. If specialisation is defined, for the present, as concentration on the manufacture of one product, then the directory material shows that the proportion of specialised firms was indeed slightly increasing over the period under discussion, as table 2, 2. demonstrated.

1877	1245 out of 1721 firms made only one product, or 72%
1892	2783 out of 3755 firms made only one product, or 74%
1907	2582 out of 3429 firms made only one product, or 75%

TABLE 2, 2. Percentage of specialised firms.

It would appear, from table 2, 2, that the engineering industries were already highly specialised by 1377, and became slightly more so by 1907, the movement being extremely slow; specialised firms formed only 3% more of the industries in 1907 than they had in 1877. This evidence is entirely contrary to any hypothesis which postulates that the engineering industries were still largely unspecialised by 1870; indeed were one, fancifully, to extrapolate the observed trend backwards in time one would reach 1657 before the industry was 50% specialised. The explanation for these unlikely results is that table 2, 2, is based on aggregate figures. Undue weight is given in such an aggregate calculation to any component industry or product group which is both large and highly specialised, since its large absolute total forms a large proportion of the total number of entries, and distorts the percentage of specialisation upwards. Two of the largest groups in all three years, agricultural implement makers and small arms makers are in fact highly specialised. Given this type of bias in the aggregate statistics, it is necessary to look at the proportion of specialised firms within each product group. The results of this disaggregation are given in appendix 2, 2. In sum, the average degree of specialisation, (summing over product groups and dividing by the number of groups, for each year), was 45% in 1877, 47% in 1892 and 49% in 1907. It should be remembered that these figures are biased downwards by the presence of small product groups with low specialisation in such the same way as the figures in table 2, 2, were biased upwards by the large groups with high specialisation; it is comforting that the trend is similar in both cases.

Whichever set of results is taken as the correct level of specialisation in the engineering industries, it is apparent that the trend is towards greater specialisation, but that, in both cases, the movement is rather slow. The levels achieved in the second set of results would appear to be more in keeping with the qualitative evidence.

The directory data can also be used to establish the numbers of products made by firms in the engineering industries. The results of this analysis are given in table 2, 3. :

	No. of firms.	Mean no. of products made.	No. of firms with more than 1 product.	Mean no. of products made.
1877	1721	1.46	476	2.66
1892	3755	1.53	972	2.03
1907	3429	1.50	847	2.00

TABLE 2, 3. Number of products made by engineering firms.

The results in table 2, 3, suggest that, in so far as specialisation is to be equated with a reduction in the average number of products made by firms in the engineering industry, the first period from 1877 to 1892 showed a slight reverse movement, and the period 1892 to 1907 a slight movement in the direction of specialisation, this being true for all firms as well as for firms with more than one product. These results do not demonstrate that the tendency was for any one actual firm to increase

and then decrease its number of products in this way; they merely show the average size of all firms. It is possible however to look more closely at trends in the 496 firms who appeared in both 1877 and 1892, and the 976 who appeared in both 1892 and 1907. (These are distinct groups; only 272 firms appeared in all three years.) The 476 firms who appeared in both 1877 and 1396 were responsible between them for 867 entries in 1877 and 1140 entries in 1892. The average number of products made by these firms thus increased from 1.75 to 2.30. The 976 firms who appeared in both 1892 and 1907 accounted for 1985 entries in 1892 and 1887 entries in 1907, the average therefore falling from 2.03 to 1.93 per firm. It is clear therefore that the rise up to 1892, and the fall up to 1907 observed in the aggregate figures given in table 2, 3, held true also for the individual firms whose history can be traced. (The 272 firms appearing in each of the three years show a similar trend, the average for them being 1.36, 2.51 and 2.40).

It will be apparent, from the figures given in the first column of table 2, 3, that the majority of firms appearing in 1892 and 1907 had not appeared in the directory for the previous date (1877 or 1892) and conversely that the majority of firms appearing in 1877 and 1892 had disappeared by the following date; there was, in other words, a high degree of turnover in the industry. (There were 85 firms who appeared in 1877 and 1907, but not in the intervening year 1892.

The possible causes for such a switch from engineering, and a return to it, will be discussed later in this chapter). Since there was this high degree of turnover, it is interesting to look at the characteristics of the firms who managed to survive in the industry. Of the 1721 firms appearing in 1877, 496 survived until 1892, or 28.8%. Similarly 976 of the 3755 firms appearing in 1892 survived to 1907, or 26.0%. When the firms are split into the specialised firms and those making more than one product, it appears that the unspecialised firms had a higher chance, although not very much higher, of surviving. Over the period 1877 to 1892 29.6% of the unspecialised firms survived, as opposed to 28.2% and 25.2%. The differences seen between unspecialised and specialised firms is obviously slight, but it is at least arguable that to produce more than one product did not place a firm in a disadvantageous competitive position. A more detailed analysis of these results would involve exploration of the differing survival rates and degrees of specialisation of different product groups, and the possible relations between these two factors.

A further complication, which cannot be explored at any length here, is the effect on specialisation, and on the turnover rate in the industries, of the changing geographical distribution of the engineering industries during these years. It is apparent that the industry was becoming less centralised during this period. In 1877, 58.9% of the entries came from towns which had

more than 1% of the entries for this year, and this percentage dropped to 51.3 in 1892 and 46.7 in 1907. Much of this fall may be accounted for by the growth of the agricultural machinery industries, which were naturally often located in the small country towns. It is however clear that, particularly between 1877 and 1892, the growth in the number of engineering firms, from 1721 to 3755, was accompanied by a widening of the geographical bases of the industry, since in 1877 only 48 towns had more than 10 entries, while by 1892 the number had risen to 98. There was, as with the figures given in table 2, 3, and perhaps for the same reason, (the reduction in the no. of entries per firm), a fall to 1907, when only 79 towns had more than 10 entries. Although these towns remained the location of the majority of the industry (75% of entries were from them in 1877, 71.3% in 1892 and 66.2% in 1907), their relative importance was diminishing. It is possible that the spread of the industry into new areas was conducive to the maintenance of some unspecialised firms, who could provide a variety of goods for local markets in which specialised firms could not make a living. Confirmation of this would, however, require a more detailed study, probably taking in other years than those covered here.

Any movement within the engineering industry towards the merging of previously separate firms would of course bias the directory figures, making it appear that specialisation in the industry had decreased when in

fact two previously specialised firms had merged organisationally, but not necessarily in their methods of production. There is however little evidence of any widespread merger movement in engineering during the period before 1914, the only major example being the combination of the Armstrong and Whitworth companies in 1897. Only three engineering firms, Armstrong Whitworth, Vickers Sons and Maxim, and William Beardmore, appear in Dr. Payne's list of the 52 largest British companies in 1905, perhaps suggesting that engineering firms in this period did not grow large by combination with competitors, and did many of the other firms on Dr. Payne's list.[9]

Study of the directory materials on the structure of the engineering industry during the period from 1877 to 1914 thus does not give a great deal of support to the view that engineering firms were becoming markedly more specialised. Although a slight trend towards specialisation is evident in table 2,2, as table 2,3 (and in particular the second half of that table) shows, the trend at least among the larger firms appears to be to move away from, rather than towards, specialisation on the manufacture of only one engineering product.

This disparity between the evidence of the directories and the views of those who have studied the qualitative evidence on this subject may however be the result of

9 Payne, P.L. "The Emergence of the Large-Scale Company in Great Britain, 1870-1914", Econ. H.R., 2nd series, vol. XX,3, December 1967, pp. 539-540.

the use of different definitions of the term 'specialisation'. In the quantitative material presented up to this point, specialisation has been taken to mean the concentration by firm on the manufacture of one of the products listed in appendix 2, 1. Another type of specialisation, concentration on the manufacture of a particular sub-type of one of these products, cannot be discussed through consideration of the directories, although it will be considered at other points in this work. Two further types of specialisation remain to be discussed, and it is possible that the redefinition of specialisation in one of these ways may provide a means of reconciling the qualitative with the quantitative evidence.

The first of these two further types of specialisation is the concentration on a range of products which present technically similar problems of design and manufacture, although they may differ greatly in their ultimate use. An example of such a class of products is the range of different types of steam engine. Professor Rosenberg has suggested that the similarity of technique exhibited by many industrial processes during this period was a potent factor in the technical progress of the metal-using industries :

> "Metal-using industries, therefore, were continually being confronted with similar kinds of problems which required solution and which, once solved, took their place in short order in the production of other metal-using products employing similar processes" 10

10 Rosenberg, N. "Technological Change in the Machine Tool Industry, 1840-1910". J.of Econ. Hist., vol. XXIII, 4, 1963, p.425.

In view of this 'technical convergence', it seems likely that firms would grow by the addition to the range of products which they made of further products whose manufacture involved similar problems. Thus firms would 'specialise', not in one type of machinery, but in a range of similar types. As Professor Rosenberg points out, analysis of industry in these terms involves discarding :

> "..the familiar Marshallian approach, involving as it does the definition of an industry as a collection of firms producing a homogeneous product, - or at least products involving some sufficiently high cross-elasticities of demand. For many analytical purposes it is necessary to group firms together on the basis of some features of the commodity as a final product;..."11

The phrase "on the basis of some features of the commodity as a final product" raises the second question of the degree to which firms 'specialised' by producing only the requirements of the particular customer or customer industry. In this case, firms would produce not a single, homogeneous product, but a range of products, of machinery in the case of engineering, which would be used by a customer to produce a particular product. An example of this might be machinery for the manufacture of small arms, which involved the manufacture of a range of wood and metal-working machinery, the individual machines in the range having very little in common with each other, and much more in common with woodworking or metal working machinery used in totally dissimilar processes. Thus one can imagine a firm, and Greenwood and Batley in fact approached close to this, which made small-arms machinery and, partly based on the technical 'spin-off' from arms machinery, a great range of wood and metal working tools. Another example of such a 'specialisation'

11 Rosenberg, N. op.cit., p.422.

in a range of products used by one single group of customers would be the firms which made in conjunction cranes, hydraulic machinery, pumping machinery and marine steam engines, all intended for the shipbuilding trades.

To test the hypotheses that these two further types of specialisation were present in the engineering industries during the period covered by the directory material involves discarding not only the Marshallian concept of an industry but also the rigid definitions of product groups established by the compilers of the directories. It involves looking not at the degree of specialisation within each product group but rather at the nature of the observed links between different product groups, in other words at exactly which products were made in conjunction. There is one difficulty in such an enquiry which needs to be noted at this stage; the simple combination of product groups which seem to be closely related will, solely by the operation of combination, produce higher degrees of specialisation, (specialisation being measured as the percentage of firms making only one product, according to the method used earlier in this chapter.)[12]

12 This can easily be demonstrated. Imagine two products, x and y, each made by 100 firms, and each 20% specialised, in that 20 firms make only x, and 20 firms make only y. 60 firms, however, make both x and y, leaving 20 firms who make x and another product which is not y, and 20 firms who make y and some other product which is not x. If one combines x and y into a new product group, z, this will contain all these firms, and will total 140 firms (since the 60 firms making both x and y will not be counted twice.)
Of these 140 firms 100 will specialise in product z, (20 who made x and something else, and 20 who made y and something else). The degree of specialisation of product z will thus be 71%, so that by the act of combining these two groups the specialisation proportion has been raised from a mean of 20% to a single figure of 71%.

It is apparent therefore that a simple combination of products in terms of these two further types of 'specialisation' needs to be treated with some caution. A further difficulty in combining the directory categories is that some products were closely connected with more than one other product group. For example, pumping machinery was useful in docks and on ships, and was therefore made by firms catering for these maritime uses; it was also useful in mines, and so was made by firms making mainly mining tools and machinery.[13] Any combination of categories would therefore have to involve some splitting of old categories to achieve a meaningful result, and since firms often made more than two products the split might have to be three-, four-, or five-way. The last difficulty is caused by the large number of products; to set out all the possible single combinations of products involves the construction for each year of a table with at least 400 cells.

In view of these difficulties, and since a full analysis of the structure of the engineering industries is outside the scope of this work, only a few summary results will be presented here. It must be emphasised, however, that this shortened treatment of these combinations between products does not represent any judgement on their importance; the study of such combinations is in fact the only possible method of analysing fully the possible existence of specialisation by technical process or by customer group.

13 Kelly's Directory Material for 1907. There were 126 manufacturers of Pumping Machinery, of whom 6 also made marine engines, 18 cranes, 15 mining machinery, 15 hydraulic machinery, and 3 rail and mine tools. 56 made pumping machinery alone.

In what follows a link between two products is said to exist when at least one firm made these two products in conjunction, although in practice the existence of a number of firms doing so is needed to establish the strength of a link between two products. It is assumed that firms acted rationally, so that the decision to make two different engineering products in conjunction was made deliberately. If this assumption is too extreme when applied to each single firm, then the fact that a number of firms make a similar decision helps to confirm that some rational process underlay their joint decision.

Table 2, 5 sets out the summary information obtained by a study of links observed in the directories.

Year	A No. of products	B No. of links	C No. of single 10% links	D No. of double 10% links
1877	37	590	116	38
1892	52	1021	208	102
1907	45	838	158	82

TABLE 2, 5. Links between engineering products.

A This column gives the number of product groups in each year.

B This column gives the number of combinations actually observed.

C This column gives the number of combinations in which the number of firms making such a combination is greater than 10% of the number of firms in either of the product groups.

D This column gives the number of combinations in which the number of firms making such a combination is greater than 10% of the number of firms in each of the product groups.

Note : Columns B, C, and D represent successively restrictive assumptions of rationality on the part of the firms involved in such combinations. Column B is the set of results to be used if it is assumed that all such decisions to combine were rational, none being random. Column C is the set useful under the assumption that some of the decisions are random, but that when at least 10% of the producers in one group decide to make another specified product then it is probable that there is some rationality behind their decision. Column B shows the results when the reasoning behind the results in column C is extended, rationality being assumed only when at least 10% of each of the products linked made that combination.

It should also be noted that each link is counted twice, that is once as a link between product 1 and product 2, and again as a link between product 2 and product 1. This double counting has computational convenience, and can be eliminated by halving each figure in columns B, C and D.

It can be seen, on the basis of the information in table 2, 5, that the importance of the double links, those in which the number of firms making both products was at least 10% of each product (col. D in table 4, 5),

was increasing over the period. This is especially true when the double links, (col. D) are expressed as a proportion of the single links (col. C), as in table 2, 6.

1877	52.3%
1892	49.0%
1907	52.2%

TABLE 2, 6. Double links between product groups expressed as proportion of single links. (Col. D of table 2, 5, as % of col. C).

There were developing, it can be seen, a larger number of specialisms which were cutting across the traditional, directory defined, definitions of products. The existence of groupings of such specialisms, indicating the existence of groups of products which were commonly manufactured together, presumably for some reason, can be seen in the material, although there are considerable difficulties in quantifying their strength and development. Table 2,7, presents, as an example, a group of products whose manufacture seems often to occur in conjunction, and other groups, the tool-making trades, the makers of various types of electrical goods, the textile machinery makers, and railway goods makers are other examples which can be discerned. In all of these groups, as in that shown in table 2, 7, there is an obvious mixture of combinations which seem to relate to technical similarities (the types of steam engines) as well as to ultimate user.

	1.	2.	3.	6.	8.	17.	28.
1.		27.2	9.3	12.8	16.5	9.3	14.3
2.	71.1		15.5	14.4	21.6	8.1	19.3
3.	79.4	44.1		20.6	47.0	20.6	44.1
6.	57.8	25.0	10.9		19.6	10.9	17.2
8.	37.2	18.6	12.4	5.4		16.3	35.7
17.	30.7	10.2	7.9	7.9	23.9		29.6
28.	20.5	10.5	7.1	5.2	21.9	12.4	

TABLE 2, 7, An example of links between groups of products in 1877.

Notes. (a) Each figure represents the percentage of the total number of firms listed in the vertical border who also made the product listed along the horizontal border. Thus 71.1% of firms making product 2 also made product 1, and 27.2% of firms making product 1 also made product 2.

(b) The products included were (numbered as in Appendix 2, 1).

1. **Fixed steam engines.**
2. **Portable steam engines.**
3. **Pumping steam engines.**
6. **Marine steam engines.**
8. **Cranes.**
17. **Hydraulic machinery.**
28. **Pumping machinery.**

On the other hand, the impression given by a study of the tables of links for each year does suggest that diversity rather than a neat classification characterises the links between different product groups. In 1877, counting each link twice as is done in table 2, 5, there were 1332 possible links between the 37 different product groups, of which 590 actually occurred. It is clear that to achieve so many different links a number of firms must have been making a variety of different products, and many of the links must surely have been the result of chance. It is difficult to explain in any other way the two firms who in 1877 made guns with joiners tools, the firm which made agricultural implements and cotton machinery, the three firms who in 1907 made agricultural implements together with marine steam engines, or the firm who made boot and shoe machinery and cranes. Such diversity points not to a steady move towards specialisation, but rather to a fluid situation in which the engineer was prepared, and able to turn his hand to a multiplicity of products if only someone would ask him to do so.

This discussion has deliberately been short, since it is intended simply as a background to the more detailed study of developments within the machine-tool industry. It is however apparent, even from the results which have been given, that the traditional picture of a gradual evolution from general engineering firms, metal-jobbing firms as Professor Saul has called them, to the specialised firms of the nineteenth century has to be seriously modified. It is clear that many firms were specialised,

but it is also clear that many of the larger firms were making a very wide range of products, and that in a number of cases it is difficult to find any rational explanation of the group of products which a firm chose to make. It is further clear that, among the multi-product firms the tendency to add new products was as strong, during the period covered by the directories, as the tendency to specialise on one product. The directory material does not, as has already been pointed out, give any information on the degree to which firms were specialising their production within the rather broad directory classification, that is if they were beginning to make only particular sizes or types; it seems likely that there were such trends in some groups, and there is, for instance, a traditional division between heavy and light machinery producers in the electrical machinery industry and in machine tools.

The picture which emerges is inevitably one of diversity; some firms moved towards specialisation, in one form or another, and others did not. The evidence does however have a number of implications which need further consideration. It is firstly clear that the concept of 'an industry' is of little use in studying the organisation of production in engineering. One has instead to examine the diversity of pressures, technical advantages, the needs of customers, the predilections of an entrepreneur, which determined the mixture of products which a firm might decide to make. It is secondly necessary to revise radically ideas about

the concept of entry to and exit from the manufacture of a particular product. It is clear that there were many kinds of entries and exits which could be made, and the difficulties facing a firm wishing, for example, to begin the manufacture of machine tools, would differ very greatly according to which previous products had been made. The evidence implies that the engineering industries were much more fluid in their composition than a traditional industrial classification would imply. Instead of a strict definition of producers or non-producers of a particular product it may be necessary to classify firms as firstly actual producers, secondly potential producers if demand conditions made it worthwhile for them to enter, and thirdly firms who would never become producers of this product. Finally difficulties arise, on the basis of this evidence, for any explanation of the weaknesses of British engineering in these years which is based on a failure to specialise; it can indeed be argued that the fluidity of the industry, the quick response which was possible to changing demand or technical change since firms were equally at home with a number of products, was a positive advantage, which would have been lost in a situation of narrow specialisation.

The machine tool producers.

It is now possible to look more closely at the structure of the producers in one branch of engineering, machine tools. It has been argued that the concept of an industry as a collection of firms making a homogeneous

product is of little relevance to a consideration of the engineering industries before 1914. It is therefore necessary to consider, not some hypothetical machine tool industry, but rather the characteristics of those firms who, given suitable demand conditions, were prepared to make machine tools. The number of firms who could have made machine tools, in the sense of having the skills and the machinery to do so, was very large indeed; indeed the fact that many engineering producers were prepared, either regularly or when they needed a specific tool, to turn their engineers to design and make the tool, must have hampered the efforts of the more specialised machine tool producers to build up their market. The willingness of engineering firms to make their own tools was not confined to the older, traditional firms; Professor Saul has shown that the American-owned Singer Company made the majority of its own machine tools right up to 1914.[14]

Thus in a sense the potential number of machine tool producers comprised the whole of the engineering industries. It is however obvious that the cost for many firms of producing machine tools for sale, as distinct from for their own use, would have been very great, and they cannot be considered as serious potential entrants to the industry. It is necessary to establish some more workable definition, and that which is most easily at hand is that the machine tool industry was the firms who agreed to be listed by the compilers of Kelly's directories, as producers of machine tools. It may be objected that this is much

14 Saul, S.B. "The Market and the Development of the Mechanical Engineering Industries in Britain, 1860-1914". Econ. H.R. 2nd. series, vol. XX, 1, April 1967, p.124 table 5.

too broad a definition, that many of these firms were old, inefficient, sold only a few machine tools, made them only as a sideline, and so on. These objections do not have much force; all those firms who would, if asked, make machine tools served as competition to the firms, relatively fewer in number, who specialised in such production.[15] This was particularly true because customers bought machine tools not primarily on the basis of price, but because a tool suited their purpose.

Furthermore a producer of textile machinery might be in a better position to design and make a machine tool that would be useful to other textile machinery producers than would a machine tool producer faced with demands from a number of industries. In the general machine tool field the specialist machine tool producer might be at more of an advantage, but even here local ties and the well-known dislike of customers for standard tools might reduce his lead.

The machine tool industry (to use the term industry for convenience) will therefore be defined as all those firms who were classified by Kelly's directories as machine tool producers. For this more detailed study, 22 editions of the directory were used, and the total numbers of machine tool producers found in these 22 years is given in table 2, 8.

15 Directory material. There were 59 specialised machine tool producers in 1877, 45 in 1892 and 57 in 1907. This was 33.7% of the total number of machine tool producers in 1877, 19.1% in 1892 and 25.7% in 1907.

Year	No. of producers.
1870	197
1874	228
1877	216
1878	273
1882	277
1883	224
1884	313
1887	258
1888	256
1891	228
1892	249
1893	279
1895	290
1897	282
1899	318
1900	306
1901	334
1903	357
1905	299
1907	230
1909	318
1910	244

TABLE 2, 8. No. of machine tool producers in 22 years.
Notes : Source of these statistics is Kelly's directories for the years listed. Selection of the years was partly dictated by the dates of publication, partly by the desire to get figures spaced at reasonably equal intervals, and partly by the availability of the relevant directories in accessible libraries.

The number of machine tool producers in existence at any time is of interest only in so far as it can be used to illuminate any developments in the organisation of the industry, or can be related to the general conditions of trade or the demand for machine tools. It can be observed, on the basis of the directory material, that the number of machine tool producers was highly volatile, numbers remaining normally between 200 and 300, but changing very rapidly in some periods; there is a rise of 30, for instance, between 1883 and 1884. If one can reject errors in compilation as the source of these fluctuations, then it can be presumed that some other force or forces were affecting the size of the industry, and were causing it to fluctuate so markedly during the period for which figures are available.

In the second section of this chapter the hypothesis is that the number of machine tool producers was a function of the demand for machine tools from the rest of the economy. In support of this contention, it will be argued that the large number of engineering firms in trades not dissimilar to machine tool production, and who often made their own machine tools, had created a pool of potential entrants to the machine tool industry; such firms could enter the industry when demand conditions were favourable, and leave when demand slackened. It will also be argued that at least in the early part of the period, before about 1890, entry into the machine tool industry was easy, in the sense that capital requirements were small and the technical requirements

were common to all who had been trained as engineers. Thirdly it will be argued that lack of sufficient economies of scale in machine tool production made it difficult for large firms to emerge, while the volatility of demand made it extremely risky for a firm to invest in large expansion of productive capacity; there was in fact an incentive for firms to remain small, to rely on a well-established market, and to allow marginal changes in demand to be catered for by other firms. Lastly the theory of a relationship between demand and the number of machine tool producers will be tested statistically, and the pattern of entry and exit by individual firms will be examined.

The directory material which was considered in the first section of this chapter provides evidence of the diversity of products which were made by firms also making machine tools in the years 1877, 1892 and 1907. Table 2, 9, shows the products which were so linked with the manufacture of machine tools. It cannot be argued, on the basis of this table, that all the firms making products which were linked with machine tool manufacture could without any cost have begun to produce machine tools. But the number of links does argue that there were many firms who were technically competent to undertake machine tool production, even if they chose not to do so. All such firms were, in a sense, potential producers of machine tools. If trade conditions changed, if their branch of the industry became depressed, if machine tool production offered higher profits, if they developed for their own use a machine tool which could be sold to others - in all

Product made in Conjunction With Machine Tools.	No. of Firms making Machine Tools with products listed.		
	1877	1892	1907
1. Fixed steam engines	28	24	11
2. Portable steam engines	8	5	3
3. [illegible] steam engines	3	10	5
4. Power looms	2		
5. Steam engines (unspecified)	5	1	
6. Marine steam engines	2	3	3
7. Cornish steam engines		5	3
8. Cranes	9	13	5
9. Gun implements	2	1	2
10. Guns, rifles and pistols.	3		
11. Machine tools (specialised firms)	59	45	57
12. Electrical machinery		1	1
13. Woollen machinery		3	1
14. Tools (unspecified)		4	
15. Electric dynamo			3
16. Mining machinery	4		3
17. Hydraulic machinery	2	10	9
18. Wood working machinery	2	14	8
19. Printing machinery	2	2	1
20. Agricultural implements		1	2
21. Locomotive steam engines		5	2
22. Traction engines		1	1
23. Boot and shoe machinery	63		4
24. Lathes and tools	14	65	90
25. Edge tools	6	16	11
26. Cotton machinery	2	4	2
27. Joiners tools	5	12	9
28. Pumping machinery	1	6	5
29. Paper machinery			3
30. Nail and mine tools	1	31	23
31. Worsted machinery	1	4	
32. Ploughing engines	1	1	1
33. Rail wagons	2		
35. Sewing machines		3	1
36. Hosiery machinery	2		
38. Ammunition		1	4
39. Hand tools		142	81
40. Agricultural engines	1		
41. Typewriters	11		
42. Coal cutters	6	17	11
43. Elec. etc. machinery		2	1
45. Oil mill machinery		1	2

TABLE 2, 9. Products made by firms making machine tools.

Note : The totals, summing each column, and higher than the figures given in table 2, 8 because a firm might make more than one other product.

these conditions such firms might enter the field of machine tool production. Indeed several of the machine tool producers entered the industry for just such reasons. Thomas Ryder and Sons, for instance, a leading machine tool firm which still survives, was founded in 1865. Until the death of George Ryder, the son of the founder, in 1893, the firm made machinery for the textile industry. In 1893, however :

> "the peak of development of the textile machinery industry had already passed, and his sons Tom and George, both of whom were minors, were faced with a very difficult situation when they succeeded their father. An obvious alternative line of business was the building of machine tools, since the firm had always made those required in the works, and had supplied a limited number to other companies.... The machine tool building side of the business was therefore expanded, and a range of lathes...was introduced". [16]

The firm of J. Parkinson and Son of Shipley came to machine tool manufacture because of the need of a special-purpose machine tool to produce sewing machines, which were the original products of the company when it was founded by Joseph Parkinson in 1867. No money could be spared to buy the special-purpose milling machine which was needed, so a machine was designed and built in the works by Parkinson and one of his foremen, based on the latter's memories of a Brown and Sharpe universal milling machine. The company also made lathes for amateur turners, and machine tool production came gradually to take up the major part of the work of the company.[17]

16 Sidders, F.A. "Machine Tool Building in Britain - 4. Thomas Ryder and Son Ltd, Turner Bridge, Bolton". Machinery, vol.99, Dec.27, 1961, pp. 1[illegible], 1491.

17 Sidders, F.A. "Machine Tool Building in Britain - 27. J. Parkinson and Son (Shipley) Ltd, Shipley, Yorks". Machinery, Feb.17, 1965, pp. 351, [illegible].

Alfred Herbert Ltd., the largest British machine tool produoer, grew out of a steam engine building firm, and came into machine tool production by accident when Alfred Herbert secured the agency for a French patent of great value in the manufacture of tubes for the fast expanding cycle trade in Coventry. On the basis of his profits from this patent the company began to make machine tools for the cycle trade.[18]

It was possible for engineering firms to enter machine tool production because the requirements in skill and capital equipment for machine tool production differed little from the requirements for other branches of the engineering trades. The skills would be available to anyone who had served an engineering apprentice, in whatever branch of the industry. In fact a large number of the founders of machine tool firms had served an apprenticeship in other areas of engineering, turning later to machine tools. Alfred Herbert was apprenticed, after turning down a career in the church, to the Leicester crane-building firm of Joseph Jessop.[19] Frederick Pollard, founder of Frederick Pollard and Co. Ltd. of Leicester was an apprentice with the same firm.[20]

18 Papers of Sir Alfred Herbert. "Machine Chasers" - a typescript autobiography. Section headed "Alfred Herbert Ltd," pp.4-5. After describing his acquisition of the steel tube agency Sir Alfred concludes "It was our good fortune to make a sufficient profit from the tube business to set us on our feet, and we used it to extend and equip our growing machine tool industry."

19 Papers of Sir Alfred Herbert. "Machine Chasers" - typescript. Section headed "Apprenticeship".

20 Sidders, P.A. "Machine Tool Building in Britain - 2. Fredk. Pollard and Co. Ltd., Corona Works, Leicester". Machinery, vol.100, April 11, 1962, p.827.

George Richards, founder of the company that bears his name, had been trained by a Swedish firm building woodworking machinery.[21] The origins of the machine tool builders will be further considered later, but for the moment it is clear that no technical training other than that needed for other engineering trades was required; indeed, familiarity with other trades to whom machine tools could be sold was a positive advantage. Not only would the technical problems of the prospective customer be known, but the personal contacts on which so many of the machine tool makers relied to sell their machines could be built up during apprenticeship, to be capitalised upon later.

Just as the skills of machine tool building could be acquired by a general engineering training, so the general tools and equipment of an engineering firm were all that was needed to undertake machine tool production. This is clear from the large number of firms in other branches of the industry, like Singers, Parkinsons, or Ryder's who built their own machine tools. It was very unlikely that a firm which had been engaged in the manufacture of some other type of machinery would not have the requisite tools, or could not buy or make them. The foundation of Willson Lathes of Halifax shows the small amount of capital equipment which was needed to enter the industry. The three founders had a lathe, a hand drilling rig and various hand tools. They began by making a horizontal borer and a planing machine,

21 Sidders, P.A. "Machine Tool Building in Britain - 7 George Richards and Co. Ltd., Broadheath, Cheshire". Machinery, vol.100, March 23, 1962, p.705.

and with these made the lathes which the company was set up to produce. No new premises were needed, the workshop being in a cellar underneath a warehouse.[22] This story is perhaps exceptional, especially at such a late date as 1897, but it does demonstrate that equipment was unlikely to be a barrier to any established firm wanting to set up as machine tool builders.

Firms could, as these case-histories demonstrate, enter the field of machine tool production quite easily. The material from Kelly's directories suggests that they could also leave the industry temporarily to engage presumably in the manufacture of some other product, returning to machine tools at a later time. Such movements away from the back to the industry are less often recorded in the written histories of firms. One example is the firm of Fraser, of Arbroath. The firm had been founded in 1832 to make sailcloth, but by 1870 :

> "As the demand for sailcloth declined, with the increasing use of steam power for ship propulsion, some members of this generation of Frasers developed new textile manufacturing processes.... The general engineering activities of the Fraser company stem from the early interest and wide experience in the design, development and construction of textile plant. Starting as an extension of the mechanics' shop, normally associated with the larger canvas factories of the late 19th century, the engineering works has continuously developed. Among early products were industrial steam engines for use in coal mines and vertical drilling machines."

22 Green, E. "Machine Tool Building in Britain - 21. Willson Lathes Ltd, Halifax." Machinery, June 3, 1964 p.1263.

The firm however turned away from machine tools early in this century to the manufacture of machinery for processing jute, returning to machine tools at the beginning of the war.[23] Whitworth's were said in 1874 to be completely occupied with arms machinery, although they almost certainly returned later to the manufacture of machine tools.[24] It is also difficult to demonstrate conclusively why firms left the industry for good, since so many of those who did so disappeared completely; one that did not was the Wolseley Company, which had come into the machine tool industry from the manufacture of sheep-shearing equipment. In 1901 they employed 400 men in the manufacture of motor cars and machine tools, but by 1910, it was said "The machine tool business had been practically dropped".[25]

It can therefore be demonstrated, that many of the machine tool firms entered the field from other branches of the engineering industry. It can be seen that such entry, and conversely their exit if demand failed, could be rapid, especially if the company already made machine tools for its own use and was setting out, in response

23 Wilders, P. . "Machine Tool Building in Britain - 21. Giddings and Lewis-Fraser, Ltd., Arbroath, Scotland". Machinery, Nov. 11, 1951.

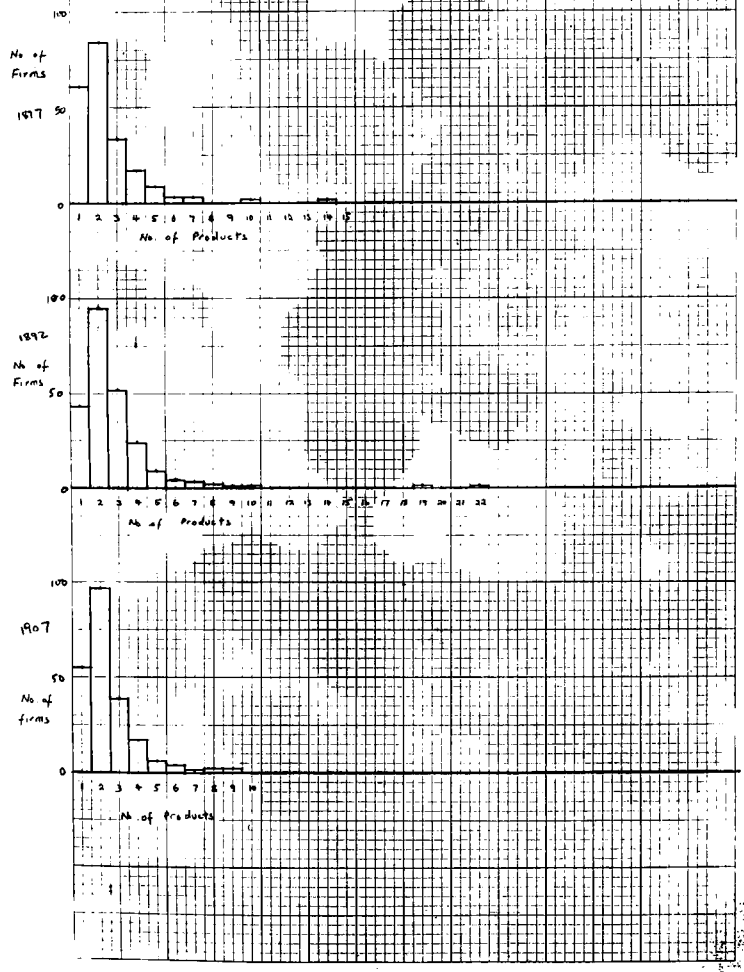
24 Fontaine, E. Machinery exhibited at Vienna, 1873.(Paris, 1874), p.127., gave as the reason for Whitworth's failure to exhibit machine tools at Vienna that the firm was making only arms machinery, but at least two other writers describe Whitworth tools later in the century, in terms which suggest they were of recent manufacture. Rose, . Modern Machine Shop Practice (London, 1[illegible]-7, vol. 1, and Holley, C. . . ., Practical [illegible] (London, 1885),p.[illegible].

25 In a description of the firm in Appleton's New [illegible]., July 1910. .1357

to demand, to sell some of them. Such firms were in a position of strength, since they could at any time decide which was more profitable, to use the machines in their own works, or to sell them to others in the industry. It is interesting that in the examples which have been quoted, the switch was not normally total; the firms made a few tools at first, sold some of them, and gradually moved to specialising in machine tools, but in many cases retained some of their production in the old field. Thus the firms continue to appear in the trade directories in both categories, specialising in one or the other as market conditions suggested. It is also clear from the material in the trade directories that many firms made more than one other product, so hedging their bets even further, and giving themselves the ability to concentrate their attention, their labour force and their machinery on any one of a number of fields. Table 2, 10, shows the number of machine tool firms making one, two or more other products in 1877, 1892 and 1907, and it is clear that many firms were involved in a number of other fields of production.

It was thus easily possible for engineering firms already in existence to move into machine tool production; the establishment of a machine tool firm from scratch was also a reasonably easy task. As has been said, the technical knowledge required would be available to anyone who had served an engineering apprenticeship and it was not necessary to have large sums to invest in the purchase of machinery. Admittedly, the advent of special-purpose

TABLE 2, 10 NUMBER OF PRODUCTS MADE BY FIRMS MAKING MACHINE TOOLS.



machines, the broadening of the range of tools, and the changes made necessary by the coming of high-speed steel did make it necessary to have some capital available, but it was normally possible to start with a few tools and finance purchase of more out of profits. Similarly, the firm could be established in a small workshop, probably rented, and a factory built for the purpose when business justified it. The experience of James Archdale is probably typical; the business was founded in 1363.

> "His first works were at Cozells Street, Birmingham, and he and two boys formed the original staff. As the business expanded, larger premises were taken at Tindall Street, which later also proved inadequate, and a site was then acquired in Ledsam Street, where building started in 1379"26

By the end of the century the capital requirements were certainly increased, and the prospects of the small man setting up in the engineering business were viewed gloomily by a writer in 1907 :

> "The conditions are very different in the engineering world today from what they were thirty or sixty years ago, when the men who are pointed out as examples started for themselves. The development in manufacturing processes that was initiated in America, but which all the world have now adopted, is against the small manufacturer. When fitting was done almost entirely by hand, right from the casting, and not too well done then in many cases, things were made in small numbers, and small manufacturers, especially those who could be relied upon for good fitting, had a good chance, and earned good money. Now all that is changed. The fitting, or assembling as it is more properly called, forms only a small part of the work; the major work is done by machines, and it is nearly always a necessity of the case that

26 Sidders, C.H. "Machine Tool Building in Britain - 9. James Archdale and Co. Ltd., Blackpole, Worcester". Machinery, April 25, 1962, p.937.

> "a large number shall be made, because the machine costs a good deal to buy and to prepare for each separate article."27

A major difficulty was the cost of financing the work between the time of receiving the order and its completion, since many machine tools would take some months to build, and it would also often be difficult to secure payment until some time after the tools had been delivered.

> "If he is fortunate, the young business man may get his money in in less than twelve months, but it is not wise to rely upon it"28

as S.F. Walker pointed out, and, to him, the difficulty of keeping the works supplied with orders was one of the main reasons for an engineering firm accepting all the work that was offered to it, rather than specialising.[29]

These difficulties of the small engineer and the new entrant pose the question of why the normal unit of production in the machine tool field remained small, of why the field was not taken over by the large firms with their specialised, advertised products. There certainly were such large firms by the 1890s, as Professor Saul has demonstrated, and they grew larger up to 1914.[30] Some grew very large. Alfred Herbert

27 Walker, S.F. Starting an Engineering Business, The Practical Engineer, vol. 35, No. 1053, May 17, 1907 pp.613-4.

28 Walker, S.F. Starting an Engineering Business, II, The Practical Engineer, Vol. 35, No. 1058, June 7, 1907, pp.712-3.

29 Walker, S.F. loc.cit.

30 Saul, S.B. "The Machine Tool Industry in Britain in 1914" Business History, vol. X, 1, January 1968, pp.26-7.

had 2,000 employees in 1914, and alone was responsible for 11% of the total output of machine tools recorded in the Census of Production in 1907.[31] But the majority remained, up to 1914 and beyond, far smaller than this, with a few hundred workers and, in most cases, still under the control and day-to-day direction of the founder or his family. This latter characteristic provides one explanation for the failure of the industry to form larger units. From an early period, in the days of Maudslay, Whitworth and Nasmyth, the lead in machine tool production had been taken by inventors, convinced of the superiority of their own tools, and unwilling to accept any limitation on their activities. Charles A. Porter described an interview with Whitworth in which the great man produced a:

> "frank statement that he divided all other toolmakers in the world into two classes, one class who copied him without giving him any credit, and the other class who had the presumption to imagine that they could improve on his. His feelings towards both these classes evidently did not tend to make him happy." 32

It is clear that machine tool makers such as Whitworth would not have taken easily to rationalisation and amalgamation. And it is also clear that machine tool making, with its emphasis on technical skill and inventiveness, attracted to it men who valued the ability to follow their own ideas higher than commercial success.

31 Saul, S. B. *op. cit.* p. 42, and see above footnote 6.

32 Porter, C. T. *Machine Tools and Machine Tool Appliances*, (New York, 1903), p. 107.

The importance of control by the inventors and their families should not be over-rated, since there were a number of other reasons for the failure of the machine tool industry to develop large units. One reason was the volatility of demand for machine tools. Graphs 3.2 and [illegible],3 (see pp. below) show graphs of the output of several of the leading machine tool firms in this country, and it is clear that there must have been many periods in which these firms were working well below capacity. The volatility of demand in an industry notorious for the violence of its cyclical fluctuations meant that many entrepreneurs were unwilling to risk expansion of their factories to cope with peaks of demand, for fear that they would be over-extended when the slump came. Archdale's rapid expansion so frightened his first partner, James G. Arnot, that he removed his money from the business.[33] Even when the owners of the firms were willing to expand, it was often difficult to raise money to do so, as Greenwood and Batley found when they undertook a large rebuilding of their factory in 1889.[34] Faced with the risks of volatile demand, many machine tool firms preferred to remain small, relying on an established market, and making no effort to attract custom.. In 1900 the Engineer commented editorially on this tendency:

> "there is not a single machine tool works of the higher class in this country which is not as stable as any similar American works. Why? Because the majority of our makers work at large profits in a close market; they know their customers

33 Information from Mr. Clements, a former employee of James Archdale and Co. Ltd.

34. Greenwood and Batley Ltd. Directors Minutes. Numerous entries during 1889 and 1890.

> of [illegible], and their customers know them and their [illegible]. The American making less profit on his manufactures, and working in a market which may desert him for a rival at any moment, is evidently in a worse position... The machine tool makers of Manchester will tell you... they make for established customers, and [illegible] employment from them and a certain number of casual clients without hysterical endeavours to attract new purchasers'.[35]

Such an attitude was not conducive to expansion, but it was often justified on these and similar grounds, another being the expense of employing salesmen and producing catalogues for the few chance orders that might result. The chance to exhibit at the great foreign exhibitions was also sometimes refused on the grounds of the great expense which might result, and the loss of production time when the machines for exhibition were being made.[36]

It seems likely, in view of the experience of other industries, that specialisation and the formation of larger units would have followed in spite of these difficulties, had there been significant economies of scale to be achieved by such a change. It is however, dubious whether there were large economies of scale to be achieved. This question will be investigated at a later stage on the level of the individual firm, but the qualitative evidence suggests that the prevalence of one-off orders, the requirements of many customers that special adornments or attachments should be fitted

35 'Editorial on "British and American Methods", [illegible], [illegible], August 31, 1900, [illegible].

36 [illegible], [illegible], commenting on the Vienna Exhibition of [illegible], note that 'the reason given for the non-appearance of many (British) firms was that they had been very busy for preceding months'. _Report on Machine Tools [illegible] at the Exhibition_. (U.S. Official reports, [illegible], Washington 1875).

to their tools, and the very wide range of types and sizes which machine tool makers were expected to manufacture, made it difficult to achieve economies of mass production. Some firms certainly did break through, by specialising rigidly in particular tools which they could make in longer runs, but the majority were content to make short runs, and to confine mass production to a few standard items such as lathe beds. Even such firms as Alfred Herbert, famous for the degree of specialisation in their production, regarded a run of four or five machines of a particular type as quite a long run, which did not often occur.[37] Most firms, in fact, however large their factory might be, continued to behave as if they were jobbing craftsmen, selling and designing each tool to suit the buyer.

It is also likely that the commonly noted low price elasticity of demand for machine tools inhibited efforts to achieve such economies of scale as did occur. Machine tools were commonly ordered as they were needed, price changes having little effect on the timing of orders, and the choice between different tools was made on the basis of suitability for the job, delivery times, experience of other tools from the same maker, and similar largely non-price criteria. [illegible] Orcutt mentioned one of these criteria:

> "It is one of the vexations of the machine tool business that customers put off ordering until the last minute. Having once decided, however, time of delivery becomes where the order is to be placed"[38]

37 Information from [illegible], former Technical Director of Alfred Herbert.

38 Orcutt H.F.L., "Machine Shop Lay-out in Europe and America", Engineering Magazine, Vol. 17, 109, [illegible].

and another engineer, A.F. Provert, explained that :

> "The average buyer, if convinced that a certain machine is superior or is better adapted for doing his class of work, will not let the matter of price stand in the way of obtaining it." 39

Thus competition in the machine tool industry was conducted, except perhaps for the most simple tools which could be widely produced, far more in non-price terms than by price competition. Although there would still remain an incentive for firms to maximise their profits by reducing costs through scale economies, it is likely that they would seek to achieve profit maximisation by raising their prices to the highest level which their customers would bear without complaining. Thus the low price elasticity of demand for machine tools would remove a major incentive to adopt whatever economies of scale did exist.

The lack of price competition, the importance of other forms of competition and in particular of the right contacts with customers, and the failure of many established firms to take advantage of possible economies of scale, made it possible both for new firms to enter the industry and for them to compete immediately with the established firms. Since the barriers to entry were so low, it was possible for firms to enter the industry in response to marginal changes in demand, particularly since many of them were already established in other branches of the engineering industry, to which they could return if demand slackened.

39 "How Machine Tools are sold. A conversation between Mr. A.F. Provert and the Publisher of _____ October 1906, p.243. Mr. Provert was described as having "had many years experience of trade conditions on both sides of the Atlantic, as sales Manager for some of our largest manufacturers,

One must consider whether the conditions which have been described, and the conclusions which have just been restated, applied throughout the period under review, and throughout the country. It has been noted that the capital requirements for entry probably increased over the period. On the other hand, the growth of new industries, such as the cycle trade which gave Alfred Herbert his start, increased the demand for machine tools, and particularly the demand for new types of tools not made by the established producers, such as the light mass production tools, milling and grinding machines. The appearance of new customers in this way widened the opportunities for potential machine tool producers and must have acted to some extent as a counterpoise to increasing capital requirements. In any case, the change in this respect was small, particularly in view of the failure of the larger, established producers to take advantage of any economies of scale which it was said, were being demonstrated across the Atlantic.[40] Given these small, and often opposed, tendencies in the conditions of entry, it seems reasonable to treat the period roughly as a unit.

The question of whether the country can be treated as a whole is in some respects a more complicated one. There is no doubt that there were defined areas of machine tool production, and that each area was regarded as having its own peculiarities and characteristics, down to the exact skills which were taught to apprentices.[41]

40 See below, ch. 7.

41 Mr. Clements, a former employee of James Archdale and ... mentioned that James Archdale, trained in the North of England, used slightly different methods with hand tools from those customary in ... an ...

This regional specialisation persisted right through the period. In 1867 Engineering commented :

> "It is generally known that engine r'. tools made in Scotland are somewhat different in their style and design from the tools made in the neighbourhood of Manchester and Leeds, the two great centres of machine construction in England. Tool makers in Scotland, who have principally to supply the extensive demands of marine engineers and [illegible] in their own locality, are, by the nature of the heavy work for which their machines are intended, induced to look to great weight, massive framings and very large castings in shape of foundations or base plates, rather than to that elegance of form and that economy of material which gives to the modern tools of the first toolmakers in Manchester and Leeds their style and characteristic appearance." [42]

During the period before 1914 new area of machine tool production emerged in the Midlands, but the regional differentiation remained strong. The History of the Ministry of Munitions commented that before the First World War machine tool production was in four areas, Lancashire which "at one time had the reputation of producing the best quality tools", Yorkshire which produced as much in quantity but of a lower grade, the Midlands which made large numbers of tools for repetition work, and the Clyde with "a flourishing industry in tools of the heavier types".[43]

It is clear from statements such as that quoted above from Engineering, that the regional differentiation in machine tools was to some extent the result of regional differences in demand. It is not possible to discover, however, exactly how tied machine tool makers in those

42 Engineering, vol. 23, 1867, p. 370.

43 History of the Ministry of Munitions, vol. VIII, part III, Engineering Supplies, p. 93.

ere were to the demands of particular industries. It is possible that the major firms were so tied, dependent on a regular stream of orders from particular customers, like the tool-makers of Manchester whose experience was quoted above, but that marginal changes in demand would be catered for by less specialised firms. Greenwood and Batley certainly made tools for customers all over the country and from a variety of industries, but they may not have been typical.[41]

It is clear that the arguments stated at the beginning of this survey of the machine tool industry are at least not rendered entirely implausible by the qualitative evidence. It remains to attempt to test the hypothesis, that the number of firms in the machine tool industry is a function of the demand for machine tools.

In order to test for the existence of this relationship it is necessary to have estimates of the size of the industry, which have been given above on the basis of the directory material, and of the demand for machine tools. The Balfour Committee despaired of the attempt to estimate the latter quantity, commenting that :

> "There exist, so far as we are aware, no statistics which enable a comparison to be formed of the output of British engineering works at any two periods." 45

It is certainly impossible to estimate machine tool production at any point during the period from 1850 to 1914, with the exception of the single figure for 1907. Nor do the British trade statistics allow of any estimates of imports or exports, as machine tools were not accorded a separate category.

41 See below, Ch. .

45 Balfour Committee, 1918.

It is therefore necessary to test the hypothesis indirectly. The production of machine tools was one sector of the production of machinery in general. Moreover, machine tools were used to produce that other machinery. It is therefore not entirely unreasonable to use, as a rough indication of changes in demand for machine tools, estimates that are available of the production of machinery in general. The most convenient such estimate is that given by Cairncross in his book on 'Home and Foreign Investment', and used by A. Feinstein, and by Mitchell and Deane, in their estimates of domestic capital formation during this period.[46] Cairncross has pointed out the dangers of this estimated series, and it is used with caution, simply because it is the best available.

The relationship between demand for machine tools and the number of machine tool firms will be tested by simple linear regression. It is common in econometric investigation to transform one or both of the variables logarithmically, on the assumption that proportional change of one variable in relation to the other is a commonly observed relationship. In this case, both the form of the scatter diagram obtained by plotting the variables against each other, and the nature of the hypothesis suggest that the relationship is linear, that an absolute change in demand produces an absolute change in the number of machine tool firms, at whatever level of demand the change occurs. Demand, following the Cairncross series, has been expressed in units of £ million, the limit of their accuracy, but the variables have not been further transformed.

46 Cairncross, A.K. "Home and Foreign Investment, 1870-1913" (Cambridge, 1953).

The regression equation to be estimated is thus :

$$Y = A + Bx + u.$$

where Y is the number of machine tool firms, x is the demand for machinery, A is the intercept term or constant, and u is the error term.

On the basis of the directory figures and Cairncross' index the estimated equation is (standard errors in brackets) :

1. $y = 11.44 + .029\ x$
(1.7) (.717)

Total # of firms - constant

The coefficient of determination R^2, (representing the proportion of the variance of the independent variable y explained by the variance of the independent variable x) is $R^2 = .43$. The regression coefficient is significant at the 1% level, and so is the F value from the analysis of variance. It is necessary especially in time series data of this type to test for the existence of serial correlation in the error terms, which would indicate the violation of assumptions underlying regression techniques. The test using the Durbin-Watson method,[47] gives d as 1.02, which is larger than the D_U of the Durbin-Watson table at the 5% level ($D_U = 1.54$); the hypothesis of positive serial correlation can therefore be rejected.

absolute changes

46 continued
the [illegible] in table 37, .1[illegible], and discussed on pp. 1[illegible]-15. It was discussed by M. Gilboy Feinstein in "Income and Investment in the United Kingdom, 1856-1914" Economic Journal, June 1961, and reprinted with additions by Feinstein in B. R. Mitchell and P. Deane, "Abstract of British Historical Statistics" (Cambridge, 1962) pp. 365-73.

47 Durbin J. and Watson G. S., "Testing for serial correlation in least squares regression, II", Biometrika, Vol. 38, 1951, pp. 159-178. An assumption in original the use of the Durbin-Watson test is that the observations are successive and spaced at equal intervals. In this case this assumption is violated, since the period between observations varies; it is however unlikely that this seriously distorts the value of the test.

Although the results so far obtained are significant, and the hypothesis of a linear relationship between demand and the number of machine tool firms can therefore be accepted, it is interesting to investigate whether the accuracy of the estimation can be improved by the addition of other explanatory variables, particularly since Cairncross' index is likely to be an imperfect estimator of demand for machine tools, rather than for machinery in general. Moreover, Cairncross' estimate is also of home consumption of machinery, while it is known that there was quite a large export trade in machine tools, and the production of machinery for export would also have employed machine tools; a variable representing export demand might therefore increase the accuracy of the prediction. Finally it may seem unlikely that a growth in demand would be coincident with an increase in the number of machine tools; one might expect a lag in response in the formation of firms, so that lagged values of the independent variables might be better estimators than the values in the same time period. A series of regressions was therefore run employing a variety of dependent variables. This procedure cannot be justified in terms of strict statistical theory, since one should be testing a relationship defined in advance, rather than stating the relationship after doing the tests. It is however, an acceptable procedure in this case, since the hypothesis remains in each case that demand changes caused changes in the number of firms; one is simply varying one's definition of demand.

The following regressions produced results significant at at least the 10% level :

2. $y = 235.30 + 5.73 x_1 - 2.22 x_2$ $R^2 = .4844$
(30.93) (2.03)[1] (1.[illegible])[2]

3. $y = 210.21 + 4.5 x_1 - 1.21 x_2 - 2.[illegible] + .[illegible]$ $^2 = .5593$
(31.93) (2.7[illegible])[1] (2.57)[2] (2.[illegible])[3] (.[illegible])[4]

4. $y = 222.7 + 3.[illegible] - 1.1 x_2 - 3.27 x_3 + 3.[illegible] + .[illegible]$
(32.91) (3.[illegible]) (2.1)[2] (2.21)[3] (.[illegible]) (.37)[4]
$^2 = .[illegible]$

where x_1 = gross value of machinery for domestic use (Cairncross)[48]

x_2 = other gross fixed capital formation (Feinstein)[49]

x_3 = gross mercantile shipbuilding (Feinstein)[49]

x_4 = gross capital expenditure by railways (Feinstein)[49]

x_5 = net exports of machinery (Cairncross)[48]

An increasing number of machine tool firms on other combinations of these variables, or on their lagged values, produced non-significant results.

It is clear from a comparison of the estimated regression equations 1 and 2 that the addition of x_2, the 'other gross fixed capital formation', does help to explain a greater amount of the variance of the dependent variable, R^2 rising from .4844 to .5572. It is further clear from equations 3 and 4 as compared with equation 2 that the addition of further variables makes no significant difference to the accuracy of the estimation, so that there is no point in including them in the regression equation.

48 Cairncross, A. K., op. cit.

49 These series are estimates by Feinstein reprinted in Mitchell and Deane, loc. cit.

The choice thus lies between equations 1 and . Both are significant at the 10 level of the F statistic from the analysis of variance. On the other hand the standard error of the regression coefficient of x_2 in equation 2 is over half the size of the coefficient itself; this makes the significance of the coefficient rather . To be safe, therefore, it seems better to fall back on the highly significant relationship established in equation .

Having done so, it is necessary to ask why the other variables did not have a significant effect, and in particular why export demand had a negligible effect. It can be argued that a characteristic of all those trends which did not have any significant effect, railways, shipbuilding and export demands, is that they were likely to be continuing demands which would build up a relationship between the customers for these goods and their . Marginal changes in demand would be catered for by those suppliers, rather than by new firms, who would not have the specialised knowledge or the contacts with the customers required to break into these markets. The demand represented by x_1, gross value of machinery for domestic use, would be of a much more general character, and marginal changes in that demand would draw the response which has been hypothesised. Thus it is entirely consistent with the hypothesis that x_1 should be the main determinant of the size of the .

It should be noted that these results accord equally well with each of two . These are firstly that initially stated, that the number of machine tools firms

was a function of demand for machine tools. Secondly there is an alternative hypothesis that the number of machine tool firms was a function not of demand for machine tools but of demand for machinery in general, which created expectations of orders and encouraged machine tool producers to set up in business (looking at the situation in a period of rising demand). In other words, the second hypothesis is that firms entered the machine tool industry not in response to orders to machine tools but in response to the general state of the engineering industry. Unfortunately, the lack of direct evidence on the production of machine tools makes it impossible to distinguish between these hypotheses; fortunately, the choice between them does not affect markedly the conclusions which can be reached about the structure of the machine tool industry and the way in which it changed over the period from 1850 to [illegible].

The results which have just been obtained relate to the total number of machine tool firms, which is seen as a function of the total demand for machinery in the economy. It is however also of interest to examine more closely the ways in which the total number of machine tool firms changed, since this throws light on the hypotheses which have earlier been mentioned of ease of entry and exit, and on the practice adopted by some firms of switching into and out of the industry as demand conditions change. Figure 2, 12 shows a breakdown of the changes in the industry.

Time Period	A.	B.	C.	D.	Total
1870-74	-68	0	+99	+29	+31
1874-77	-61	0	+49	-12	-12
1877-79	-44	+9	+92	+48	+57
1879-82	-93	0	+97	+ 4	+ 4
1882-83	-96	+6	+37	-59	-67
1883-84	-28	+50	+67	+39	+89
1884-87	-87	+1	+46	-41	-40
1887-88	-33	+6	+15	- 8	- 2
1888-91	-56	0	+23	-29	-29
1891-92	-22	+1	+42	+20	+21
1892-93	-19	+7	+42	+23	+30
1893-95	-40	+5	+46	+ 6	+11
1895-97	-53	+6	+39	-11	- 8
1897-99	-31	+11	+56	+25	+36
1899-1900	-38	+3	+23	-15	-12
1900-01	-22	+6	+44	+22	+28
1901-03	-24	+5	+42	+23	+18
1903-05	-38	+1	+29	-59	-
1905-07	-93	+1	+13	-70	-69
1907-09	- 7	+54	+41	+34	+88
1909-10	-100	0	+24	-76	-76

FIGURES 9, 12, Change in numbers of machine tool firms.

A = Fall in number of firms existing at beginning of each period.

B = Number of re-appearances of firms which had been in industry before this time period.

C = Number of firms entering industry for the first time.

D = Net change within period/total no of firms in industry as a result of A and C.

It is apparent that there was a high degree of turnover in firms in the machine tool industry, consistent with the high degree of turnover observed in the engineering industry as a whole; whether this turnover is peculiar to machine tool manufacture, or to engineering, or is a feature of the whole of British industry during this period cannot be established until similar studies are undertaken on other industries. Within this high turnover, which in itself is confirmation of the ease of entry and exit which has been postulated, the movements of the series given in figure 7, 12, do support the view that the number of firms in the industry varies according to some exogenous factor, which, it has been suggested, is market demand. Thus there is a positive correlation of .1535 between columns A and B in the table; the tendency is for periods in which few firms left the industry to be periods in which old firms are returning to the industry. There is no significant correlation between exit of old firms and entry of new ones, but it may be suggested that this is because there is a replacement effect, (some of the change in both A and C is accounted for by an old firm being replaced by a new one); when the net effect is calculated, as in column D, this net effect has a correlation of 0.1535 with column B, again supporting the view that firms return to the industry when it is also attractive to new firms, presumably in conditions of rising demand. The correlation of each of the variables A, B and C with the total change are also reasonably high, at .7[illegible], .6800 and .5501 respectively. The total correlation matrix is set out below in figure 7, 13.

	A		C	D	Total
A	1.0000	0.1185	-0.0405	.7656	.
B	0.1185	1.0000	0.1092	0.4585	.6800
C	-0.0405	0.1092	1.0000	0.6117	.5501
D	0.7656	0.4585	.6117	1.0000	.
Total	0.7925	.6800	.5501	.	.

Table 7, Matrix of correlation coefficients of the variables listed in figure 7, p.

The evidence which has been presented is thus consistent with the hypothesis which was stated at the beginning of the second section of this chapter. Both the statistical evidence showing a connection between demand for machine tools and the number of machine tool producers, and the qualitative evidence of contemporaries, point to an industry which did not exhibit many of the characteristics, of greater size of unit, increasing specialisation, aggressive competition, which are so obvious as used to be characteristic of a growing industry. New economies of scale were possible, except perhaps by a radical transformation into a pattern like that of the highly specialised American firm. Those large firms which might have been capable of such a change or of such economies as were possible did not choose to exercise their strength to acquire new custom, but were content to rely on a stable market, allowing marginal demand to be catered for by newcomers to the industry. The industry remained predominantly one of small firms, as there were few firms anxious to take the trouble or risk entailed in extending their market share. Competition was severely

restricted in certain fields by the existence of special relationships between producers and consumers, which will be examined later, and such competition as there was was largely in non-price terms. The machine tool industry which had emerged as a distinct entity by 1914 thus had many points in common with the embryo industry of the middle of the nineteenth century; in the remainder of this work its efficiency and performance within this almost unchanging structure will be investigated.

APPENDIX 2, 1. roducts ncluded in the sa nle fro the
terial in olly's irectory of orch ts and anu .

1. Fixed steam .
2. ortable steam .
3. umping steam on ines.
4. owe Looms.
5. team engines (un ecified).
6. arine steam on ines.
7. ornish steam on ines.
8. .
9. Gun implem .
10. Gun, rifle pistol.
11. Machine to .
12. Electrical c inery.
13. oolle machi ery.
14. Tools (ec).
15. Electri l ynamo.
16. in ry.
17. lie c ery.
18. wo ing ach .
19. rintin c ery.
20. .
21. .
22. .
23. Boot and oe c inery.
24. Lathes and .
25. dge to ls.
26. otto c ery.
27. Joiners tools.
28. Pumping m ry.
29. aper c ery.
30. Rail and ine tools.
31. orsted c ery.
32. ail carri es.
33. on .
34. Rail .
35. owing i .
36. osiery .
37. Con .
38. .
39. Hand tools.
40. ricultural en ines.
41. Sheep shears.
42. ypewriters.
43. to re.
44. , hemp nd silk waste c ery.
45. ll ill c inery.
46. Ordnance ma hi ery.

1907
output
chains?

Appendix A, 1 continued :

21. Shells.
22. [illegible].

The numbers assigned to the products are for convenience; the order has no significance.

APPENDIX 2, . % of specialised firms within each product

[illegible].

Product	1877	1892	1907
[illegible]. Fixed steam	[illegible]	[illegible].3	[illegible].
[illegible]. Portable steam	[illegible].	[illegible].	[illegible].
[illegible]. [illegible]ining steam	11.[illegible]	[illegible].	[illegible].
[illegible]. Power loom	[illegible].7	[illegible].	[illegible].
[illegible]. [illegible]	[illegible]	[illegible].	[illegible].
[illegible]. Marine steam	[illegible]	[illegible].	[illegible].
[illegible]. [illegible]rnish steam		[illegible].	
[illegible]. Cranes	[illegible].[illegible]	[illegible].7	[illegible].
[illegible]. Gun [illegible] to onto	[illegible].	[illegible].[illegible]	[illegible].1
[illegible] [illegible]n, rifle, pistol	[illegible].	[illegible].[illegible]	[illegible].
[illegible]. [illegible]chine tools	[illegible].7	[illegible].1	[illegible].
1[illegible]. [illegible]ectrical [illegible]chinery		[illegible].3	
1[illegible]. [illegible]oollen [illegible]chinery		[illegible].	[illegible].
1[illegible]. Tool manufacturers	7.	[illegible].	7[illegible].
1[illegible] Electric [illegible]ynamo		[illegible].	
1[illegible]. [illegible] [illegible]achinery		11.5	51.
1[illegible]. Hy[illegible]. [illegible]lic [illegible]achinery	[illegible].	[illegible].8	[illegible].
[illegible]. [illegible]	[illegible].	11.[illegible]	[illegible].
19. [illegible] [illegible]chinery	7[illegible].	7[illegible].	[illegible].
[illegible]. [illegible]	31.9	[illegible].2	[illegible].
[illegible]. Locomotive steam		[illegible].	[illegible].
[illegible]. Traction engines	1[illegible].8	1.7	
[illegible]. Boot [illegible] Shoe [illegible]	[illegible].	7[illegible].	[illegible].
[illegible]. Lathes and tools	[illegible].	[illegible].	[illegible].
2[illegible]. Edge tools	[illegible].	7[illegible].	6[illegible].
[illegible]. Cotton machinery	[illegible].	[illegible].	7[illegible].
[illegible]. Joiners tools	[illegible].	[illegible].	5[illegible].
[illegible]. Pumping machinery	[illegible].	[illegible].	[illegible].
[illegible]. Paper [illegible]achinery	[illegible].7	[illegible].	[illegible].
[illegible]. Rail and mine tool		[illegible].1	[illegible].
[illegible]. [illegible]orated [illegible]achinery	[illegible].	[illegible].	[illegible].
[illegible]. [illegible]ail carriage	[illegible].	[illegible].	[illegible].
3[illegible]. [illegible]oughing engines		[illegible].	
[illegible]. [illegible]ail [illegible]ron	[illegible].		[illegible].
[illegible]. Sewing machine	7[illegible].8	77.[illegible]	[illegible].
[illegible]. Hosiery machinery		[illegible].	[illegible].7
[illegible]. Cannons	1[illegible].	[illegible].	[illegible].
[illegible]. [illegible]munition	[illegible].	[illegible].	[illegible].
[illegible]. Hand tools		1[illegible].7	[illegible].
[illegible]. [illegible]gricultural engine			[illegible].
[illegible]1. Shoe shears	[illegible].	[illegible].	[illegible].
[illegible]. Typewriters			[illegible].
[illegible]. Steam [illegible]	[illegible].	[illegible].6	3[illegible].
[illegible]. Flax [illegible].	[illegible].	[illegible].	[illegible].
[illegible]. Oil [illegible] [illegible]y	[illegible].	[illegible].	[illegible].
[illegible]. Ordnance		[illegible].	

How manufactured and the Calgons?

Appendix B, B, continued	1377	1092	1907
L. Shello			
L. Lorolo			
Mean	[illegible]		
S.	37	44	

APPENDIX 2, 5. Geographical distribution of the engineering trades.

In 1877 there are 48 towns with more than 10 directory entries.
1892 38
1907 79

The total number of entries from these towns was :
1877 1363
1892 4096
1907 5373

This represented the following % of the total number of entries.
1877 71.3
1892 72.4
1907 [illegible].1

CHAPTER 3
CHARACTERISTICS AND GROWTH OF THE MACHINE TOOL FIRMS.

In the last chapter the machine tool industry was placed within the wider context of the engineering industries, and its growth and development was discussed in the light of quantitative evidence on the number and origins of the machine tool firms. In this chapter the development of the industry will be examined through qualitative evidence on the origins of the machine tool entrepreneurs, on the development of individual firms, and on the market situation in which they were involved. The analysis in the last chapter has suggested that a major determinant of the number of firms in the machine tool industry was the level of demand for machine tools in the economy, but within this broad framework there was scope for many individual variations in origin, size and shape of firms; qualitative evidence alone can document those individual variations.

The major difficulty of the following type of qualitative analysis is that, normally, the available evidence relates only to the successful firms, to the leaders of the industry and to the firms who attracted the attention of the trade press. These firms formed, as has been seen, only a small proportion of the firms in the country who made machine tools, although they may have been the most forward-looking and the most technically inventive of such firms. It must therefore be remembered that the firms which will be discussed in this chapter (with the exception of the more comprehensive discussion on the geographical dispersion of the industry)

are in no way to be regarded as representative of [illegible] firms, and attempts to extrapolate from evidence on these firms to characteristics of the industry as a whole are unlikely to be reliable.

The machine tool entrepreneurs.

One of the most important features of the growth of the British machine tool industry is that virtually all the machine tool firms were formed as partnerships or firms under the control of one man, and that they remained in most cases under the close control of the original founders or their families, at least until the beginning of the twentieth century. It has already been suggested that technical training was an important pre-requisite of success in the field of machine tools, and it is clear that the majority of the machine tool entrepreneurs had served an apprenticeship in the engineering industry. In this section, the education and the experience of the entreproneurs will be described, in an attempt to elucidate any other common characteristics which might explain their success or the pattern of development of the industry as a whole.

It is difficult to find any common characteristic in the schooling received by the future owners and managers of British machine tool firms. Most appear to have received an education suitable to the social class of their parents. William Muir, for instance, the son of a farmer and building contractor, received an ordinary middle class education.[1]

1 Memoir of William Muir, Proceedings of the Institute of Mechanical Engineers, July 1[illegible], p.1440.

Richard Peacock, the son of a lead miner and engineer, attended Leeds Grammar School.[2] Joseph Whitworth Hulse, son of Whitworth's nephew and manager J.C. Hulse, was educated at Uppingham,[3] while Alfred Herbert, the son of a prosperous Leicestershire farmer, was educated first at a private school and then at Stoneygate School in Leicester.[4] On the other hand many of the machine tool entrepreneurs, particularly those from poor families, seem to have received little or no formal education. James Archdale entered a coal-mine at the age of seven,[5] James Butler began work very young as an office boy in the offices of the Halifax 'Courier' and then worked in a chemist's shop,[6] Thomas Greenwood worked in his father's machine shop.[7] Only one of the machine tool entrepreneurs, Henry Ford Kearns, the son of a professional violinist, received any form of higher education; Kearns read chemistry at London University.[8]

Although they came from such disparate educational backgrounds, the machine tool entrepreneurs had, almost without exception, one common characteristic, that they had 'served five years time' as an apprentice mechanical engineer. Some, like Archdale, Butler, James Smith of Deanfield, Smith and Grace, William Asquith, Samson Fox of Smith,

2 Memoir of Richard Peacock, M.I.M.E. Jan. 1889, p.107

3 Memoir of Joseph Whitworth Hulse, M.I.M.E. April 1893, p.315

4 'Machine Tools', manuscript autobiography of Sir Alfred Herbert, 'School'.

5 Information from James Archdale, Junior.

6 Obituary of James Ryder Butler, 'Halifax Evening Courier' August 20, 1917.

7 Information from Dr. Charles Greenwood.

8 Sidders F.R. 'H.F. Kearns and Col Ltd.', Machinery, Vol. 101, July 4, 1962, p.9.

Beacock and Tannett, appear to have financed their apprenticeship period themselves, perhaps from previous earnings or, as in Smith's case, from working in the evenings.[9] Others were premium apprentices, financed by their families, or served apprenticeships in firms owned or managed by their relations. Herbert was a premium apprentice with Joseph Jessop of Leicester, Charles Scriven was apprenticed to his uncle's firm, Goodman, Scriven and Holdsworth, Alfred Muir was apprenticed in his father's works.[10] But however they were financed, all the major entrepreneurs in the field of machine tools whose origins are known, with the sole exception of Kearns, were apprenticed as mechanical engineers.

It is at the apprenticeship stage, and even more at the stage when these men took their first jobs as trained engineers, that one of the most significant features of the training of these entrepreneurs becomes apparent. It is clear that the range of firms within which apprenticeships were served, and early jobs taken, was very small. Both Herbert and Frederick Pollard were apprentices at Joseph Jessops,[11] Archdale was an apprentice with Greenwood and Batley, and then worked for Kitson's, Walkers, and

9 For Archdale see note 5 above. For Butler see note 6 above. For James Smith see Grierson, J. 'A little far from well tilled'. For Asquith see Sidders, F.A. 'William Asquith, Ltd.' Machinery, Vol. 99, November 22, 1961, p. 1195. For Fox, P.I.M.E., Dec. 1903, p.919.

10 For Herbert see 'Machine Tools'. For Scriven see P.I.M.E., Feb. 1899, p.309. For Muir P.I.M.E. May 1902.

11 For Herbert see note 10, for Pollard, Sidders, F.A. "Prod. Pollard and Co. Ltd.", Machinery, Vol. 100, April 11, 1962, p.827.

Fowler's in Leeds before moving to Manchester to work for Hetherington and then for Tangye.[12] Thomas Craven worked for Sharp, Roberts, while Henry Bates, Thomas Elliott and Joseph Whitworth Hulse both worked for the successor firm of Sharp, Stewart.[13] Elliott, John Stirk, John Shepherd, and Thomas Craven all worked at one time for one of the Fairbairn companies.[14] Some men also worked for what seems to be an extraordinary number of different firms before setting up on their own. Whitworth worked for Crighton, Marsden, Walker and other firms between 1821 and 1825 in Manchester, then moved to London where in eight years he worked for Maudslay, Holtzappfel, Wright and Clements.[15] William Muir worked between 1829 and 1840 successively for the Catrine Cotton Co., for Henry Houldsworth, for the Hayle Foundry Company in Cornwall, for Maudslay and Field, for Bramah and Robinson, and for Whitworth.[16] John Stirk was apprenticed to Joseph March of Leeds, and then worked for Fairbairn, Shepherd Hill, Smith Beacock and Bennett, Darling and Sellers, Buck and Watkin, and Scott Brothers, before founding his own business in 1866, when he was still only 23.[17]

The explanation for this apparent concentration of experience on the part of machine tool entrepreneurs lies of course in the small number of mechanical engineering

12 Information from James Archdale, Junior, and from manuscript history of firm, compiled by Mr. Clements.

13 For Craven, Green, R.J. 'Craven Brothers, (Manchester) Ltd.' Machinery, Feb. 5, 1965, p.237, for Elliott, P.I.M.E. Feb. 1899, p.127, for Hulse see note 3 above, for Bates, P.I.M.E May 1900, p.351.

14 For Elliott see note 13, for Stirk, "Coaches, Planes & Plows", publ. by John Stirk and Sons Ltd, Halifax 1938 for Shepherd P.I.M.E. Dec. 1900, p.1039, for Craven see note 13.

15 P.I.M.E. Feb. 1887, p. 197. 16 See note 10 above.

17 See note 1 above.

firms in existence in the early part of the period, and in particular in the even smaller number of reputable firms who could be guaranteed to provide good training. It is unclear why some of these engineers should have worked for so many firms, although it may have been that a good mechanic could best improve his income by accepting offers from successive firms, rather than waiting to be promoted within one firm. Muir for instance was foreman at Sudslay and Field, assistant and representative at Holtzappfel, foreman at Bramah, and then manager at Whitworth's.[18]

A characteristic of successfulmachine tool entrepreneurs thus appears to be that they were technically trained. The importance of this is presumably related to the speed of innovation, and the importance of the invention of new machine tools; a firm could not be successful unless it could produce a stream of new ideas, new machine tools, or modifications to old tools, and this demanded technical expertise and training on the part of the managers of the firms. Technical training was obviously far more important, and regarded as such, than commercial or financial expertise. James Archdale, who by 1896 was employing about 450 people and selling machine tools all over the world, was taught to read and write only in his fifties, that is somewhere between 1839 and 1849,[19] and as has already been described, some other successful machine tool makers had little formal education.

18 See note 10 above.

19 Information from Mr. James Archdale Jnr. and from [illegible] Clements.

One result of the concentration on the acquisition of technical skill, and of the humble origins of many of the entrepreneurs, is that many of the firms were very short of capital in their early years, and particularly when expansion of the firm or its premises was needed. Although it was sometimes possible for such expansion to be financed by borrowing, - Dean Smith and Grace borrowed on mortgage in 1874, for instance,[20] - by far the most common way of raising capital was to enter into partnership or, towards the end of the century, to turn the firm into a limited company and sell shares. Archdale had a partner called James Arnot, who took out his capital on retirement, and Archdale then, to finance expansion of the works, entered into partnership with two tube drawers, John Earl and and George Horn, later buying them out.[21] James Butler financed extensions to the factory after 1887 with a partnership entered into in that year.[22] The best documented instance of a firm obtaining capital in this way is provided by John Holroyd; Holroyd had started as a manufacturer and supplier of sewing machines, but at the end of the 1880s was in difficulties after the cancellation of an order for 100,000 child's sewing machines. He was introduced by a local copper merchant to a Mr. Liebert, a Manchester export merchant, whose son Henry had been apprenticed as Beyer Peacock and had then worked as an engineer in Finland and Russia. Apparently in order to attract Henry Liebert home, Mr. Liebert agreed to put capital into Holroyd's business,

20 Grayson, S. 'A little far well tilled'

21 Information from Mr. P.A. Clements. Arnot was apparently frightened also, at the speed with which Archdale was expanding the business.

22 See note 6 above.

and a new company was formed, with Liebert as chairman, and Holroyd, Henry Liebert and another man as directors.[23] With this change, the manufacture of special machine tools, which had been allied with the sewing machine business, was greatly expanded. Another example of a partnership between an engineer and a man trained in finance was that between Thomas Greenwood and John Batley.[24] Such partnerships were of course common in British manufacturing industry from the early industrial revolution period onwards.

With the exception of such information as has been mentioned about their origin and early training, it is extremely difficult to discover very much about the machine tool entrepreneurs of the period after 1850, although for the earlier period a great deal is known; James Nasmyth had his biography written by Smiles, and other engineers were described in Smiles' "Industrial Biography" and "Lives of the Engineers", and in J.W. Roe's "English and American Tool Builders". All that can really be said is that a number of the machine tool entrepreneurs appear to have been important local figures; Frederick Peacock was M.P. for Norton, while Arthur Greenwood was an unsuccessful Parliamentary candidate in Leeds, James Platt was mayor of Gloucester, and both he and Manasseh Gledhill, managing director of the Whitworth Company, were O.B.E.[25]

23 Manuscript history of John Holroyd and Co. Ltd.

24 Information from Dr. Charles Greenwood.

25 For Peacock, P.I.M.E. Jan. 1889, p.197. For Greenwood information from Dr. Charles Greenwood and information on West Leeds Conservative Association in records of Greenwood and Batley Ltd. For Platt P.I. M.E. Nov. 1897 p.516. For Gledhill P.I. M.E. May 1899, p.267.

This type of information about the origin and experience of the machine tool entrepreneurs is obviously unsatisfactory, as it comes from so few firms, but it is at least suggestive of the type of skills required by the industry that so many of the men who have been described were technically trained. It is unlikely that this was a sufficient condition of success in the machine tool field, but it at least appears to have been necessary.

The geographical location of the machine tool industry.

It is, as the last section has demonstrated, difficult to discover anything very definite about the character of the English machine tool industry from scattered pieces of information about the entrepreneurs of the industry. Much more complete information is however available, from the business directories which were used as source materials in the last chapter, about the geographical location of the industry, and about the changes in the distribution of the industry about the country between 1850 and 1914.

Table 3, 1, below, gives the numbers of machine tool firms in each of nine areas of the country between 1870 and 1909, compiled on the basis described in the last chapter.

It is clear from table 3, 1, that, as would be expected in an industry linked to the machinery and metal trades generally, the machine tool industry at this period was concentrated in five areas of Great Britain, with a very small number of firms standing outside the main groups. The traditional centre of the industry, the north-east, remained the strongest group throughout the period, with

Year	Areas: 1	2	3	4	5	6	7	8	9	Total
1870	1	37	102	11	2	27	1	0	16	197
1874	1	53	105	18	7	33	0	0	14	231
1877	4	59	90	34	9	22	2	0	17	242
1878	8	70	106	24	8	43	1	1	22	283
1882	5	79	118	32	9	45	0	0	26	314
1883	8	69	111	34	9	39	0	0	29	299
1884	10	71	126	39	11	35	0	0	33	325
1887	4	70	111	26	6	23	0	0	25	265
1888	4	73	115	28	7	26	0	0	16	269
1891	4	65	99	28	3	20	0	0	18	238
1892	4	67	101	37	5	20	0	0	22	257
1893	4	72	114	47	6	21	1	0	24	290
1895	4	74	129	47	4	19	0	0	23	301
1897	4	77	123	54	5	19	1	0	20	304
1899	7	81	132	61	5	17	1	0	21	326
1900	7	78	133	61	6	19	1	0	23	325
1901	9	75	142	62	6	20	1	0	25	341
1903	7	73	145	62	10	36	1	0	28	362
1905	6	59	129	52	9	36	0	0	23	314
1907	7	53	118	43	9	29	0	0	24	283
1909	5	69	126	50	10	32	1	0	28	321

TABLE 3, 1. Geographical location of themachine tool industry in Great Britain, 1870-1909.

Notes : 1. Areas are :

1. Northern England
2. North-West England
3. North-East England
4. Midlands Industrial
5. Midlands Agricultural
6. London and S.E. England
7. South-West and South England
8. South Wales
9. Scotland

2. Five machine tool firms in Ireland in 1877, and one in each year from 1891 to 1901 inclusive, are included within the totals.

a heavy concentration in the West Riding of Yorkshire but other areas grew in importance during the period, reducing the predominance of the north-east. This can be seen from table 3, 2, below, which gives the number of machine tool firms in each of the five main areas as percentages of the total number of forms in a given year.

Table 3, 2, suggests that, while the north-east was still by far the largest area of machine tool production, the industrial midlands in particular were rising into predominance particularly from the beginning of the 1870s. London, the traditional centre of the industry in the early years of the century, with Maudslay, Bramah, Holtzapfel and others, had already lost its position by 1870, and continued to decline in importance although the establishment in London of many agencies for the sale of foreign tools gave London some importance which is not reflected in these figures of the number of machine tool manufacturers. North-West England, principally Lancashire, was second to the north-east throughout the period, but does not show any very marked changes over the period. Scotland also held very much the same relative position at the beginning of the period as at the end.

The explanation for this pattern of settlement of the machine tool industry lies principally with the location of its customer industries, as has already been suggested in the last chapter. The predominance of the north-east and north-west is to be explained by the demands for machinery of the textile industries, and of the other heavy industries, including shipbuilding, which were

Year	Areas :				
	2	3	4	6	9
1870	18.8	51.8	5.6	13.7	8.1
1874	2?.0	45.5	7.8	1?.3	?.1
1877	24.4	36.8	14.0	9.1	7.0
1878	24.7	37.5	?.5	15.2	7.?
1882	25.2	?7.?	10.2	14.3	.3
1883	23.1	37.1	11.4	1?.?	.7
1884	?1.?	38.8	12.0	10.8	1?.2
1887	26.4	41.9	9.?	?.7	?.4
1888	27.1	42.8	10.4	9.7	5.9
1891	27.3	?1.?	11.?	8.4	7.?
1892	26.1	?0.?	1?.4	7.?	?.?
1893	?4.?	?0.?	1?.2	7.2	?.?
1895	24.6	?.?	1?.?	.?	7.?
1897	25.3	40.4	?7.?	6.3	.?
1899	24.8	40.?	13.7	?.2	.?
1900	24.0	?0.9	?.?	?.	7.1
1901	22.0	?1.?	1?.?	?.?	7.3
1903	20.2	40.1	17.1	9.?	7.7
1905	13.?	41.0	16.6	11.5	7.?
1907	1?.7	?1.7	15.2	1?.?	?.5
1909	?1.5	?0.?	1?.?	1?.?	.7

TABLE 3, 2. % of total number of machine tool firms in each of five areas of Great Britain, 1870-1?09.

Notes : 1. Areas as in table 3, 1.

2. Areas omitted are those with numbers less than 5% of total.

situated in these areas. The importance of Scotland can also be largely explained by the Clyde shipbuilding industries, most of the Scottish machine tool firms being in that area. The decline of London reflects the fall in the importance of the capital as a seat of industry, while the rise in the number of machine tool firms in the industrial Midlands is a reflection of the growth in that area, around Birmingham and the 'Midland Hardware District' of the light metal processing industries, of small arms, the sewing machine and the bicycle. These industries began to reach full development in the 1880s and 1890s, and, as can be seen from table 3, 2, it is exactly to that period that the rise in the number of machine tool firms can be dated.

Specialisation and the products of the firms.

Writers in the engineering trade press in the late nineteenth century often argued that the machine tool firms were failing in enterprise in that they did not specialise, did not concentrate their efforts and their plant on the manufacture of particular types of tools. The topic of the degree of specialisation within the British engineering industry as a whole has already been considered, but one aspect of specialisation could not be discussed because of the nature of the material derived from the business directories. Firms could not only decide to specialise in machine tools, or in a range of engineering goods related to technical or commercial needs; they could also decide to make only one, or a very few, types of machine tool. It is this further type of specialisation which will be discussed in this section.

Two reasons were normally given by contemporary commentators for the failure of machine tool producers to specialise in particular types of tool. It was firstly alleged that, in order to maintain good relations with good customers, it was necessary for the machine tool firms to make any type of machine tool which the customer needed. In 1902, for instance, Mr. J.R. Richardson told a meeting of the Institution of Mechanical Engineers that :

> "Not only was it necessary to have on his catalogue 500 different types and sizes of steam-engines, but an infinite variety of mining and general machinery; and in addition his firm was expected to do anything required, and had to do it even if it only had to be done once."[26]

The need to make a large number of types of machine tools was apparently reinforced by the practice of British machine tool firms agreeing to equip complete factories with all the necessary tools. Craven Brothers, for instance, made a wide range of tools, and in 1894, "The Craven catalogues included almost every type and size of machine tool then known, together with large numbers of special machines,..." while one of their many activities was "supervision of the building and supply of complete machine tool installations for a number of railway workshops."[27] The American Engineering Magazine ascribed the "peculiar state of the European tool-maker" in 1898 partly to "their large export trade, and the fact that they undertake to produce every article called for by foreign enquiries or indents, where complete plants are required."[28]

26 P.I.M.E. Jan. 1902, p.57. This remark was made during a discussion on a paper by W.H.L. Orcutt on 'Modern Machine Methods'.

27 Croon, J. . 'Craven Brothers (Manchester) Ltd.' Machinery Feb. 3 1900, p.239.

28 Engineering Magazine, XVI, 1898-9, p.55. 'Machine Shop Management in Europe and America', by W.H.L. Orcutt.

English customers for machine tools were also blamed for

> "insisting upon makers constructing machines, specially designed according to the purchaser's ideas, for every little operation, instead of accepting the standard pattern, thus giving makers much inconvenience and needless trouble",

although it was argued in reply that, particularly with heavy machinery, "they had to make the machine according to the particular object for which it was intended; they could not make them by the gross."[29]

The second reason given for the failure of English machine tool makers to specialise was that it was necessary for them to make a large number of tools to 'get a turnover'. Alfred Herbert, whose firm was one of the most progressive, and was described as "a firm who, by the way, follow American methods of manufacture perhaps more closely than any other machine tool makers in this country"[30] thought that "in the early days", specialisation was not possible. In his autobiography, 'Machine Chasers' he wrote that :

> "Although our first machine tool efforts were directed mainly towards the requirements of the bicycle business, we soon began to supply machines to the much wider field of general engineering... It has often been suggested to me that we should have done better if we had specialised more intensively on a limited range of machines. There is no doubt much force in this contention, but in the early days I doubt very much whether there was scope for a growing business, which confined itself to the production of only one or two machines. Rightly, or wrongly, I was more attracted by the idea of covering a fairly wide field. The cycle business, which was our principal customer, required in those days a variety of machines and not many of them of one kind."[31]

29 Colliery Guardian, April 2,1896,vol.lxxi, no.1840,p.695. These remarks were made during a discussion on a paper by W. Dixon on 'Milling Machines', read to the Manchester Association of Engineers, March 23, 1896.

30 Engineer, vol.88, Dec. 15 1899, p.567-7.

31 'Machine Chasers' by Sir Alfred Herbert. Chapter headed 'Alfred Herbert Ltd.'

The need to make a large number of types of machine tools was reinforced by the fact that so many engineering firms, as has been mentioned in the last chapter, made their own machine tools, and in fact bought only the most specialised machines from outside, machines which their mechanics' shop was not capable of making. In these cases, the machine tool firm was effectively acting as a consultant engineer for the customer, designing and making a special tool for a special job, or perhaps, in the case of the complete factory installations, designing and making a complete set of machine tools.

The nature of the tasks fulfilled, in this way, by machine tool firms, relates to the characteristics of the machine tool entrepreneurs and their firms which have already been described. The importance of the design function put a premium on technical skill on the part of the machine tool producer, while the necessity for close consultation meant that it was an advantage for the machine tool firm to be located reasonably near to its customers.

It is probably for this reason that some areas of this country became known for specialising in particular types of tools. The History of the Ministry of Munitions puts this clearly in describing the situation in 1914 :[32]

> Machine tool manufacture in Great Britain was, broadly speaking, grouped in four districts, where the demand for machine tools was great on account of the industries of which these districts were the centre. Lancashire was the early home of the machine tool trade, and it

32 History of the Ministry of Munitions, Vol. VIII, part III, p.38.

> one time had the reputation of producing the best quality tools. Yorkshire competed closely in quality of output, but the machinery was, with some exceptions, of a lower grade, being simpler in design and produced by a number of small makers who had not the organisation and the up-to-date methods of the larger trades. The Midlands, produced, on the whole, large numbers of machines of the type required for repetition work and suitable for use in the small arms, motor and cycle trades, while the shipbuilding and marine engineering industries of the Clyde had resulted in the development of a flourishing industry in machine tools of the heavier type in the immediate neighbourhood.

It is however very difficult to establish that there were neat divisions of this kind, when one examines the range of machine tools listed in the catalogues of individual firms, and it would seem that the divisions were impressionistic at the time and have little value today in analysing the development of the industry. Far more important, in fact, than the small degree of geographical specialisation, was the general impression of the lack of specialisation on individual tools, and of the huge range of machine tools produced by the majority of makers. This impression is also consistent with the considerable number of links between machine tool production and the manufacture of other engineering products which was described in the last chapter.

The growth and development of the British machine tool firms.

Just as it is extremely difficult to find any common factors linking the origins of the various British machine tool firms, so it is difficult to discover much comparative information on the development of the machine tool firms after their foundation. In this situation, rather than attempting to present a rounded picture of the development

of the industry, it is most helpful to present as much data as possible about the machine tool firms for whom some information has survived, before attempting to draw some general conclusions about the growth of the industry.

One of the characteristics of firms which was not often mentioned in contemporary reports, and on which information survives in the records of the firms, is employment. Table 3, p, presents as much reliable information as it seems possible to gather about the numbers of men employed at various dates. These figures cannot unfortunately be taken as entirely reliable, if only because there are, for some firms, very different figures for employment obtained from different sources; in these cases, it is not possible to know which source is correct. In the case of the Churchill Machine Tool Company, for example, Professor Saul ascribes to this company an employment figure of 100 in 1913, while the magazine '_Machinery_' said in its issue of August 14, 1913, that the firm employed 350 men on the manufacture of grinding machines.[33] Similarly, Professor Saul gives a figure of 400 men for the labour force of George Richards of Altrincham in 1913. This would seem to accord with the remark of the American consular official, W.L. Carden, in 1909, that the firm employed 500 men, but is almost certainly inconsistent with the report in _Mine, Engineering and Shipbuilding_ of June 19, 1912, that the firm employed 1,000 men.[34] It is possible that

33 Saul, S.B. "The Machine Tool Industry in Britain to 1914" _Business History_, vol. X, No. 1, January 1968, p. 27; '_Machinery_' August 14, 1913.

34 Saul, S.B. _loc.cit._; Carden, W.L. (1909), p.240; Times Engineering Supplement, June 19, 1912.

Firm	Year	Number of employees
Archdale, James and Co., Birmingham (1868)	1868	2
	1894	450
	1910	600
	1913	500
Asquith, William, Halifax (1865)	1913	350
Bennie, James and Sons, Glasgow (1853)	1913	200
Berry, Henry, Leeds (1832)	1913	200
Buckton, Joshua, Leeds (1842)	1882	300
	1913	400
Butler, J and Co., Halifax (1868)	1913	350
Churchill Machine Tool Co., Manchester (1901)	1909	100
	[illegible]	350
	1914	100(Saul)
Craig and Donald, Johnstone (1815)	[illegible]	200
Craven Brothers Ltd., Manchester (1853)	1894	450-500
	1906	550+
	1913	600
Cunliffe and Croom, Manchester (1864)	1913	200
Darling and Sellers, Keighley (1850)	1909	160
	1913	200
Dean, Smith and Grace, Keighley (1865)	c1880	150-200
	1906	400
	1913	400
De Bergue, Manchester (1836)	1913	200
Fielding and Platt, Gloucester (1866)	1898	450
Herbert, Alfred, Coventry (1887)	1887	12
	1897	250
	1898	500
	1908	1400
(1200 works, 300 staff)	1910	1500
	1913	2000
Holbrook Machine Tool Co., Harlow (c1843)	1914	100
Holroyd, John and Co. Ltd., Rochdale (1887)	1913	250
Hulse and Co., Salford (1852)	1913	400
Jones and Shipman, Leicester (1899)	1903	34
	1904	40
	1905	50
	1906	99
Kearns, H. J. and Co., Broadheath (1907)	1913	100
Kendall and Gent, Manchester (1847)	1913	350
Lang, John and Sons, Johnstone (1874)	1909	700
	1913	700
Luke and Spencer, Broadheath, (1877)	1913	100
Marsden, Samuel and Son, Manchester (1845)	1897	400
Mitchell, Keighley	1913	70
Muir, William and Co., Manchester (1842)	1894	400
	1913	400

Firm	Year	Number of Employees.
Ormerod, Hebden Bridge	1913	80
Parkinson, Shipley (1867, machine tools from 1884)	1913	400
	1914	515
Pollock and Macnab, Manchester (1905)	1913	170
Pollard, Frederick and Co. Ltd., Leicester (1911)	1912	50
Richards, George and Co. Ltd., Broadheath (1880)	1909	500
	1912	1000
	1913	400
Ryder, Thomas and Son, Bolton (1865 machine tools from 1893)	1866	40
Redman, Halifax (1871)	1913	200
Scott Bros., Halifax (1854)	1913	40
Scriven and Co., Leeds (1851)	1913	50
Smith, Hugh, Glasgow (1875)	1913	175
Smith and Coventry, Salford (1859)	1894	500
	1913	550
Smith, Barker and Willson, Halifax (1899)	1913	70
Stark, John Halifax (1866)	1913	200
Ward, H.W. and Co., Birmingham (1890)	1910	500
	1913	650
Ward, Haggas and Smith, Keighley (1870)	1913	200
Webster and Bennett, Coventry (1887)	1913	70

TABLE 3, . Size of British machine tool firms, by number of employees (date of foundation in brackets)

Notes : 1 The figures for 1913 are taken from Saul, S.B. "The Machine Tool Industry in Britain to 1914" Business History, X, 1, Jan. 1968. Appendix 1, p.42-3. They were "obtained from the firms concerned and from descriptions in contemporary engineering journals".

2 Figures other than these for 1913 were obtained from records of the firms and from engineering journals.

3 A number of well-known machine tool firms are excluded from this list, either because no employment figures are known, or because the figures include workers on other products than machine tools.

this inconsistency is the result of a failure to make a distinction between actual labour force at the time of the report, and capacity labour force at a time when the factory was fully provided with orders. In 1910, for example, Archdales were described in the Proceedings of the Institution of Mechanical Engineers as having 600 workers 'when fully employed', and Cardon, describing John Lang and Sons in 1909, mentioned that at the time of this visit they were employing 500 men, but that his was because demand was very bad; the normal work force of the firm was 700.[35] One of the first responses to falling demand, apparently, was to reduce the size of the labour force, so that the number of men employed could fluctuate very greatly over very short periods. Since it is normally impossible to know whether the figures given relate to actual or to full capacity working, or are simply incorrect, too much reliance must not be placed on the figures given in table 3, 3.

A second reason for treating the figures given in table 3, 3, with some reserve, relates to the fact of fluctuations in employment following trading conditions, in that different areas of the country could experience different patterns of demand, largely because of the fact that certain groups of machine tool firms were traditionally tied to different customer distribution. If, therefore, the figures given in table 3, 3, relate to the actual labour force of the firms at the dates given, then the figures may not be comparable as between firms, since the demand conditions, and the need for full capacity working, varied

35 P.I.M.E. July 1910, p.1307; Cardon, op. cit. (1909) Vol. I, p.213.

from area to area across the country. In 1913, for instance, all the machine tool making areas were experiencing a slackening from the boom conditions of 1912, but the decline in orders was more noticeable in some areas than in others. In March of 1913 the Midlands machine tool firms were said by 'Machinery' to be still at high pressure, while Scottish firms were returning to more normal conditions, and in April Yorkshire firms reported a general slackening. By May the Midlands were still working at high pressure, but orders to Yorkshire firms were falling off badly. An appreciable decline in orders was reported from the Midlands in August, but by September orders were increasing again in this area, although in Lancashire and Yorkshire the depression continued at least until October, by which time it was again said that the Midlands were again experiencing a general slackening in demand, while Scotland had never been as busy. By November Yorkshire and Lancashire were depressed again, while demand for tools from large Midlands firms was increasing, although the small firms were still depressed. Lancashire continued depressed until the end of the year, but Yorkshire recovered, particularly the firms at Keighley, Hebden Bridge and Sowerby Bridge. These reports from 'Machinery' are extremely difficult to interpret, based as they were on the impressions of machine tool makers who were naturally concerned not to give away secrets to their rivals; they are also apparently inconsistent with the summary of 1913, also in 'Machinery' in January 1914, in which it was said that the Midlands had had a record turnover in machine tools in 1913, that 1913 had been a very good year in Lancashire, that Yorkshire had had an exceptionally good year until September, and that Scotland

had experienced a record year. It therefore seems unwise to put too much reliance on employment figures in such a confused year.[36]

A further difficulty over the interpretation of employment figures is that of necessity they relate to the size of the labour force rather than to man-hours worked. It was thus possible for a firm, by enforcing overtime working, to vary its productive capacity markedly without changing the size of its labour force. The wage books of the small Leicester machine tool firm of Jones, Pollard and Shipman, which have survived for the period from 1903 to 1906, show that labour force grew as shown in table 3, 3; at the same time, however, actual hours worked varied very greatly. During the week ending May 30, 1903, the labour force of about 34 were each working approximately 50 hours weekly, but by the week ending Nov. 7, 1903, the average number of hours worked was between 60 to 70. By December 1904, on the other hand, hardly any work was being done, but by the following summer trade was improving and the labour force was expanding, as it was to do until the end of 1906. Since the labour force were paid at a fixed rate for a 54 hour week, and pro rata for any greater or lesser amount, rather than being dismissed if trade fell off and taken on if it improved, the actual employment figures, taken from the number of men in the wage books of the firm, give an entirely misleading impression of the actual numbers of man-hours being worked.[37] It seems likely

36 These comments on the state of the machine tool trade are taken from weekly articles headed 'News from the Shops' in 'Machinery' for 1913.

37 Information from the wages-books of Jones, Pollard and Shipman, now Jones and Shipman Ltd. The records were kindly made available to me by the firm.

that a similar situation may have obtained in other machine tool firms, but without the actual wage books it is impossible to be certain of this.

Since there are so many difficulties associated with the use of the employment statistics which have been presented, it would be extremely hazardous to attempt, for instance, to make calculations of output per man at different periods, in an attempt to gain knowledge of productivity movements in the industry. Professor Saul does make such an attempt, while acknowledging the imperfections of the data, and finds a rise in current price terms of net output per man from about £75 in the early 1890s to over £140 in 1913.[38] As he says, the sample of five firms is extremely small, but it is of interest that the rise is analagous to that for another firm, Greenwood and Batley, which is explored in a later chapter.

No other calculations can usefully be made from the employment data which has been presented. It remains to be noted, as Professor Saul does, that in general the size of the British machine tool firms, with one or two exceptions, was quite small. Only Alfred Herbert and possibly George Richards employed over 1,000 men before 1914, and Saul calculated the average size of the firms for whom he had employment figures in 1913 as 370. Surprisingly, as Saul comments, this was larger than the average American firm, which employed 300 men. Saul argues that the American industry contained more larger firms with more than 1,000 workers, although, if they did so, the average of 300 shows that there must also have been a much larger number

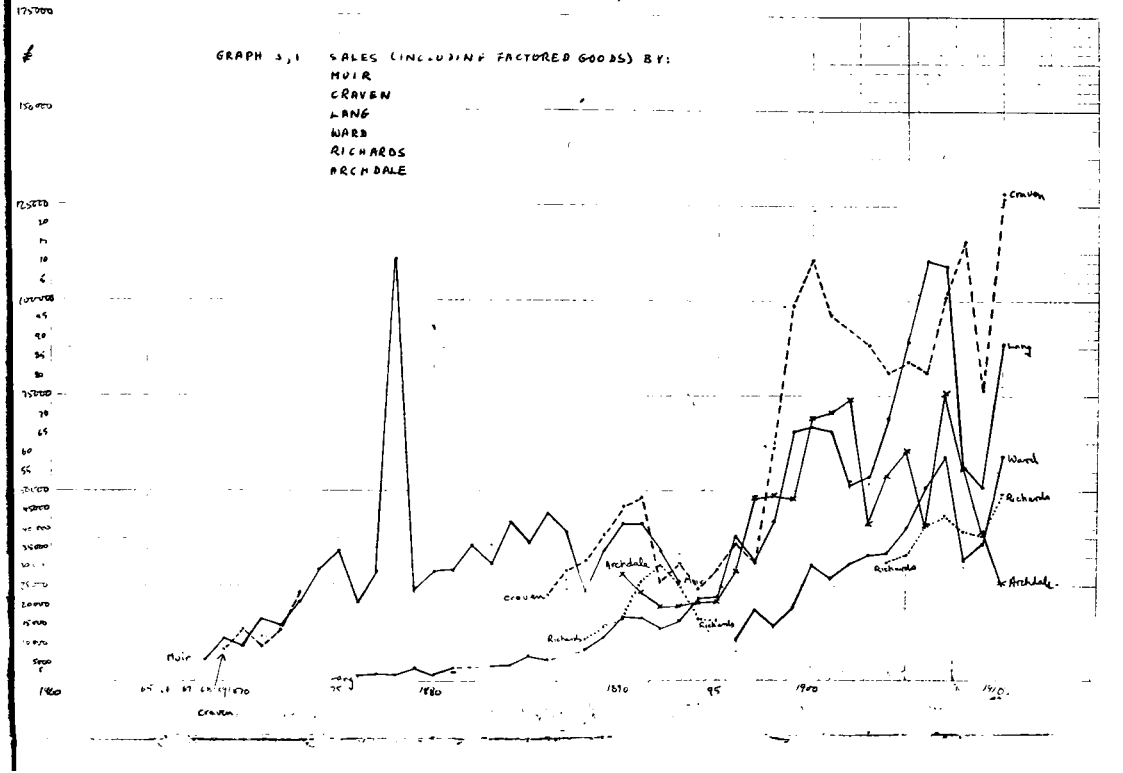
38 Saul, loc.cit., p.11.

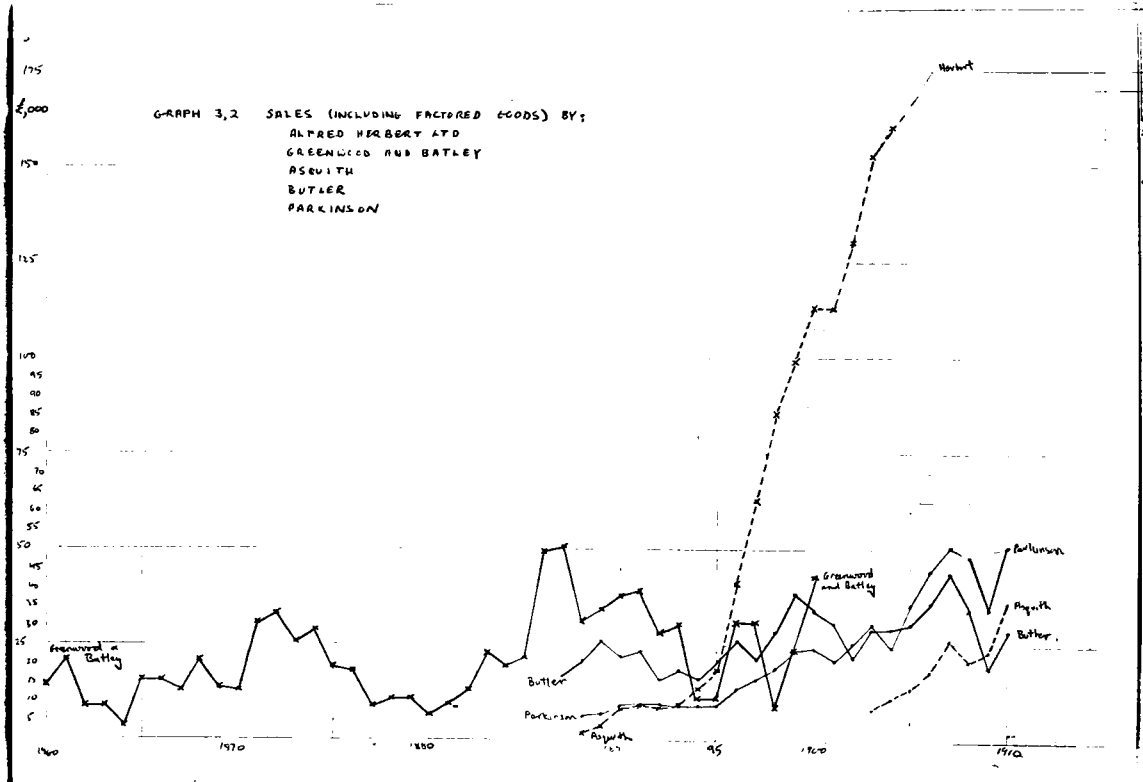
of firms employing only 100 or so men. The data is so sparse, however, and so difficult to interpret that it is difficult to be very certain whether, in terms of employment, American firms differed very much from British firms in the machine tool industry.

Employment figures are thus an inadequate guide to the development of the British machine tool industry. Unfortunately, as has already been mentioned in the last chapter, few other statistical sources do exist for the study of the development of individual firms, and those that do relate to the leading, most successful firms in the industry. Graphs 3,1 and 3,2 present such information as is available on the sales made by eleven such firms.[39]

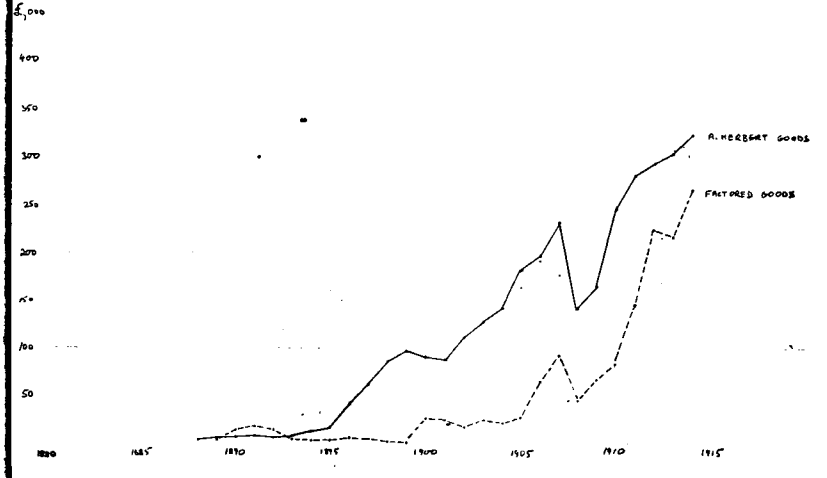
As has already been mentioned, these sales records relate to only a small proportion of the total British production of machine tools as revealed in the Census of Production of 1907. A number of the series contain not only machine tools manufactured by the companies concerned, but also factored machine tools, normally from the United States; while in some cases it is possible to separate the factored goods from the rest, in other cases it is impossible to do this; the total figure is used as a basis for the graphs as probably the best indicator for each company of its growth and position within the market. In the case of Alfred Herbert, a firm which experienced phenomenal growth partially as a result of a large volume of factored sales, it is possible to make such a separation into the components of total sales, and the results of this are shown in graph 3,3. In one case, Parkinson, the sales figures used include sales of one of the other products of the firm, vises, and it

39. I am very grateful to Professor S.B. Saul for allowing me to use the figures on which some of these graphs are based.


£
GRAPH 3,1 SALES (INCLUDING FACTORED GOODS) BY:
MUIR
CRAVEN
LANG
WARD
RICHARDS
ARCHDALE
Muir
Craven
Lang
Ward
Richards
Archdale
1880
1890
1900


GRAPH 3,2 SALES (INCLUDING FACTORED GOODS) BY;
ALFRED HERBERT LTD
GREENWOOD AND BATLEY
ASQUITH
BUTLER
PARKINSON
£,000
175
150
125
100
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
Herbert
Greenwood & Batley
Greenwood and Batley
Butler
Parkinson
Asquith
1960
1970
1980
95
1900
1910

GRAPH 3.3 SALES BY ALFRED HERBERT LTD
FACTORED MACHINE TOOLS ARE INCLUDED
WITHIN A. HERBERT GOODS UNTIL 1899.



is impossible to tell what proportion of total sales should be attributed to this product. Finally, it should be remembered that these sales figures relate to total sales, to customers at home and abroad, and that they are therefore an inadequate indicator of trends in the home consumption of machine tools.

In spite of these difficulties, it is possible to arrive at some generalisations about the experience and growth of these eleven firms. (Greenwood and Batley will be considered at length in later chapters, and their experience will therefore be referred to in this chapter only in passing.) In what follows, the growth of the firms will be described in deliberately vague terms; it would be possible, on the basis of this data, to calculate their growth rates and deviations from trend, but in view of the deficiencies of the data it seems better not to give to these imprecise indicators an air of precision, particularly since the interpretation of trends calculated over such short periods and over periods exhibiting such fluctuations is necessarily hazardous.

It is clear that, for the machine tool firms for which sales records exist, the period from 1888 to 1890 or 1891 was one of reasonable prosperity; some firms, such as Muir, Craven and Greenwood and Batley, showed quite considerable increases in sales. During the next five years, however, while the machine tool firms for which information is available showed a decline in sales or, in the case of the two smallest firms, Herbert and Parkinson, stagnation. From 1895 onwards, however there is a very substantial revival of sales, and, in the case of Herbert, this was the beginning of

period of quite extraordinary growth. The expansion in sales by Herbert, many of them factored American machine tools, should not however obscure the growth in this period of other firms, such as Butler, who doubled their sales between 1894 and 1900, Lang, who grew at the same rate as Archdale, and Craven, whose sales leaped from £24,413 in 1894 to £111,335 in 1900.

After 1900, although a number of firms continued to show an absolute increase in sales, the upward trends were markedly reduced, even in the case of Herbert. The first five years after 1900 were marked by considerable fluctuations in the volume of sales, although from about 1904 the strong upward trend was resumed in most cases, the major exception being Archdale. The next serious downturn in sales occurred, in 1908-9 and affected most firms even including Herbert, whose sales dropped from £325,877 in 1907 to £[illegible],180 in 1[illegible], though by 1910 the 1907 level had been surpassed. After 1909 sales for all these firms moved upwards, with minor fluctuations, until the outbreak of the first world war.

With the exception of the late 1880's, during which the number of machine tool firms fell slightly, the growth in these leading firms parallels the chronology of the growth of total number in the industry which was established in the last chapter, and can be closely related to the

40 Information on the sales of Lang, Craven, Ward, Richards, Archdale, Butler, Asquith and Parkinson was collected by Professor Saul, and I am very grateful to him for allowing me to use his results. I am also grateful to him for allowing me to see the records of Lang. Information on the sales of Alfred Herbert and Greenwood and Batley was collected from the records of these companies.

experience of the major customer industries for machine tools. A direct attempt to relate machine tool sales to the experience of particular industries is somewhat hazardous, since not only is it impossible to know in detail which industries were buying the tools made by these firms, but also it is not known what proportion of tools were exported to countries experiencing different economic conditions. With these caveats, however, it is clear that the expansion in the period after 1895 must be related to the home boom of this period, and in particular to the establishment of a number of new industries such as the bicycle trade, and, in the later years, to the South African war with the demand which it created for arms machinery. The slowing down in growth after 1900 can similarly be attributed to the downswing of the economy in general in this period, and the trends of the period after 1905 again closely follow the trends described by many observers in the economy as a whole, the boom from 1905 to 1907, the depression of that and the following year, and the boom of 1909 to 1914, although, as the discussion in 'Machinery' on the detailed experience of 1912 to 1913 suggests, there were differences in the experience of different sectors of the industry at this time.

It thus appears that, as was suggested in the last chapter, the demand experienced by the machine tool industry was closely related to the demand for machinery in the economy as a whole. It would be interesting to know whether demand for machine tools followed a particular path within these conditions; leading machine tool entrepreneurs have suggested in conversation that orders for machine tools do

not rise until after the onset of an upswing in general demand, since customer industries wait until they are sure of an expansion ahead before ordering new machinery. There is then, it is suggested, a hectic period of activity, followed by a cut-off in orders, and even cancellations, as soon as a downturn in general demand is thought possible. It is difficult to be certain whether such a pattern applied before 1914, particularly since there is the complication of export orders, but it does not in fact appear that the booms in machine tool sales are noticeably shorter than those in the economy as a whole. Several of the machine tool firms, in fact, show signs of revival in 1894, before the revival was perceptible in the economy as a whole, and expansion continued until the end of the general boom in 1901. The experience of the following decade also does not suggest any particular lead or lag in the demand for machine tools in relation to demand as a whole.

There remain, however, several problems about the chronology of machine tool demand and the growth of these leading firms. The first problem is the small effect which can be observed of the very serious engineering strike of 1897, which lasted in some areas for six months, and which certainly involved some machine tool firms, although it is not known whether all these firms were involved. Sales by Lang, Craven and Parkinson fell between 1896 and 1897, but not by very large amounts, and the sales of other firms rose or remained at the same level as in 1896; Herbert's growth was apparently not affected in any way (unfortunately, for this period, the sales of this company cannot be split into manufactured and factored goods.)

It seems likely that this apparent inability of the engineering strike to affect the sales of machine tools can be explained partially, on the side of the machine tool firms themselves, by the continuance of their sales of factored goods, or, in the case probably of some of these firms, by the fact that they were not directly affected by the strike. Although the strike may have led to some cancellations of orders for machine tools by British customers, this was a period of growing demand from foreign markets, and the British machine tool firms could thus sell any surplus tools abroad. One of the major issues in the strike was the 'machine question', the dispute over the introduction into engineering workshops of automatic or semi-automatic machine tools manned by semi-skilled workers. The defeat of the engineering workers on this question in the strike almost certainly led to an increased use of the new machinery, particularly in industries such as bicycles which did not have a traditionally-minded skilled labour force, and thus the engineering strike led to immediate benefits for the machine tool industry. The apparent non-appearance of the effects of the engineering strike in the statistics of machine tool sales may therefore be explained through the interaction of all these separate movements in demand.

A second problem is more fundamental to the interpretation of the statistics which have been presented in graphs 3, 3-3. In his discussion of these statistics Professor Saul argues that eight of these firms, Herbert, Ward, Archdale, Parkinson, Craven, Butler, Lang and Richards were among the largest machine tool makers in Great Britain, and he continues :

> "... above all they were those that contemporary literature and subsequent experience have shown were the most progressive in the development of high speed working, of specialisation, of the making of the new American type tools. The growth of their output, both in volume and value terms from the nineties onwards is striking testimony to the speed with which British engineering was adopting new techniques."41

Unfortunately, in the absence of knowledge of trends in output in the machine tool industry as a whole, the inference made by Professor Saul is illegitimate. For his inference to be proven, it must be shown not only that the output of these 'progressive' firms was rising, but that their share of the total market for machine tools was increasing. If it was not, then the proportion of the advanced tools pioneered by these firms to the total number of machine tools would not have been increasing. Since we do not know for more than one year (1907) the total output of the machine tool industry, nor the proportion being exported, nor the amount of imports of machine tools, nor the relative sales to home or foreign markets of the firms listed in graphs 2, 1-3, 1, Saul is on very tenuous ground; he is safe only in asserting that the growth in the sales of these eleven firms, which together in 1907 accounted for only 29% of the output of the industry, is striking testimony of the growth of these firms.

Such a criticism is of course a counsel of perfection; but it is another pointer to the dangers of generalising from a few well-known and surviving firms to the industry as a whole. It may be argued that the sales of Norbert, in

41 Saul, ... loc.cit., pp.34-5.

particular, were rising at so fast a rate, even in comparison with the other firms listed in the graphs , that the market share of that firm must have been rising. This was almost certainly true, but it must be remembered that a considerable amount of the expansion of that firm was accounted for by the expansion of Herbert's factoring business, the sale in this country of American machine tools; by 1900 approximately one-fifth of total sales were of this type. Secondly, Herbert from the very first made a considerable effort in export markets, and it is possible that much of the total value of sales represents sales abroad rather than to British industry.

A further and more fundamental criticism is that it is doubtful whether Herbert, or indeed some of the other firms were quite as progressive in all ways as Professor Saul assumed. It has already been suggested that the growth of specialisation and the development of the new 'American-type' tools did not necessarily go together, although Professor Saul links them as definitions of 'progressive'. Alfred Herbert himself argued, in the passage quoted above, that specialisation was not possible when he first made machine tools, and that the expansion of his firm was built upon traditional lines, that is on making all the tools which his customers, particularly the bicycle industry, might be likely to need. Of the other firms, it seems likely that the expansion of Archdale's was more the result of increased demand for armaments machinery, its major product, that of any particularly progressive attitudes on the part of its owner, who according to his son, retained very old-fashioned ideas of factory organisation. More generally, it will be argued in the next chapter that the different

structures of the American and British industries in this period may not have been the result of progressive and non-progressive attitudes or methods on the part of the entrepreneurs, but rather that they stemmed from the market situations of each industry. 'Progressive' needs a great deal more definition if it is to become a concept which can usefully be applied to an analysis of the machine tool industry.

Just as the sales figures of these firms reveal little about the growth of the industry as a whole, or about the components and causes of growth, the more detailed financial records of the firms reveal little about other aspects of the machine tool industry. With the exception of the records of Greenwood and Batley, the available records are the balance sheets and in some cases profit and loss accounts of a small number of firms. In the case of Alfred Herbert, profit and loss accounts and some balance sheets are available from the foundation of the firm onwards, and in the case of Muir similar figures exist, together with other financial records, for the period from 1868 to 1893. Unfortunately the use of the financial records of these two machine tool firms is open to considerable objections; firstly because the records of one firm experiencing growth which was much the fastest in the industry and of another which went out of business in 1893 do not provide a very good basis for generalisation about the industry as a whole, and secondly because of the rudimentary accounting procedures of the firms, in particular on their depreciation provisions for their fixed capital, and on their methods of valuing stocks; there do not appear to have been any

universally agreed conventions on these matters within the industry, and the courses actually adopted appear to have been highly idiosyncratic. Greenwood and Bailey, for instance, as will be shown later in more detail, valued their stocks in a different manner from their valuation of sales, thus producing an apparent increment in the value of their products when they were transferred from stock to a customer. They also adopted a procedure for writing off the value of their fixed capital which was based on the desire to be able to justify payment of dividends rather than any logical depreciation formula. Muir appear to have followed a similar policy. Further difficulties are caused, in the case of Alfred Herbert, by the failure of the firm to distinguish at various periods between factored goods and those of their own manufacture, and between the value of goods in stock and in progress. Since the value of stocks held was both high in relation to total sales and highly variable, this deficiency in preparing the profit and loss accounts makes it impossible to discover on a yearly basis any estimates of profits from the two activities, factoring or manufacturing, or to examine changes in the costs of the factors of production or their shares, although figures for direct and indirect labour costs, and for materials costs, are available.

For all these reasons, it is probably better not to attempt to utilise these financial records in any systematic way, since the data which they record are of so much lower precision than that used in other parts of this study of the industry, and it is important not to give to them a spurious accuracy.

Conclusion.

The information and analysis in this chapter has demonstrated above all the deficiences of qualitative information and the records of the major firms as sources for the economic history of the machine tool industry. It is clear that the firms who made up the industry varied very greatly in their foundation, their management, their size and their growth, and that generalisations based on the experience of a small number of them are certainly misleading.

At the same time, the picture of the industry that emerged from these qualitative and partial sources does not differ in any material respect from the general analysis based on more comprehensive sources. The features of the industry that need most emphasis are clearly diversity and fluidity, the diversity that came from the need to serve the requirements of many different customer industries and from the experiences and preferences of the entrepreneurs, and the fluidity which came from the close links of the machine tool firms with the rest of the engineering industry and the fluctuations in demand for machine tools. It has been shown that a reliance upon the experience of the leading firms in the industry may be unwise, and that neat definitions of the industry into progressive or non-progressive, or into specialised and non-specialised, or geographical groups, may hamper rather than aid analysis. Only more detailed analysis of the particular markets for machine tools, and of the characteristics of individual firms, can offer some way out of this difficulty of characterising the industry in any way, and it is this type of detailed analysis that forms the basis of the succeeding chapters.

CHAPTER 4

THE INTERNATIONAL TRADE IN MACHINE TOOLS.

In 1851 the British superiority over all other nations was, in machine tools as in many other products, unchallenged.

> "At the Great Exhibition of 1851 it (Britain) may be said to have been without a rival; the display of machine-tools then made by English houses took the world by surprise. No French and German, and even the American engineers were not prepared for such refinement of form combined with solidity of construction, the several fittings having a degree of precision never seen before, and yet constructed with such severe simplicity of arrangement in every detail, which by general consent placed England above comparison with the rest of the world."[1]

This technical superiority, which was coupled with the commercial superiority of firms like Whitworth and Nasmyth, was eroded by foreign competition during the next seventy years, and it is the purpose of this chapter to describe this erosion, to estimate its effect on British sales of machine tools both at home and abroad, and to suggest some explanation.

1 Report of the Royal Commissioners [illegible] Exhibition of 1867. (P.P. 1867-8, Pt. II, 511). Report on 'Machine Tools' prepared by John Anderson, C.E. Anderson was one of the British jurors at many of the international exhibitions of the period. Born in 1813, he worked for several of the leading British engineering firms before being appointed in 1842 to take charge of a new factory at the Woolwich Arsenal. He invented a number of machine tools for arms manufacture, and in 1856 became chief government inspector of the armstrong Gun manufactory. In 1866 he became superintendent of machinery to the War Office. He retired in 1872, was knighted in 1873, and died in 1876. (Memoir, M.I.C.E., Vol. 1876, p. 360) Further information on Anderson and his career can be found in Rosenberg, N., Technology and American Economic Growth, (1972), p.

The sources for a study of international trade in machine tools are limited, and those that exist are deficient in a number of ways. Statistical evidence on the trade is very scarce, at least until the early twentieth century, largely because the trade appears to have been small, at least in comparison with other engineering products. Some statistical evidence is available from the records of the machine tool firms' accounts, and that from Greenwood and Batley of Leeds, and the American company Browne and Sharpe, will be used below, but the extraction of such information is extremely cumbersome, and is possible only when the detailed order-books of the firm are available; the financial records of the companies, balance sheets and similar material, do not, in the British companies whose records have been examined, normally distinguish home and export sales.

Qualitative evidence is fuller than is the statistical evidence, partly because of the conviction which was held at the end of the nineteenth century that Britain was falling behind in competition with other countries, but since in most cases the information, at least on aggregate trade, was as scanty for contemporary writers as it is for an historian, the value of the qualitative statements has to be continually questioned. It has always to be remembered, for instance, that depreciating statements about the British export effort could originate either from a real failure of British commercial effort or, as is the case with many of the consular reports, from a desire to spur British exporters on to further effort. They can therefore not be taken to be entirely objective summaries of the true competitive position of the British machine tool trade.

Secondly the qualitative evidence is deficient because much of it related to technical rather than to commercial success, to the appearance of new technical refinements rather than to the volume of sales. This is particularly true of the reports of the major international exhibitions, valuable though they are as a source of evidence, and it is true of much of the comment in the trade press. A biased picture may also emerge from the comments in the trade press because of the variety of products made by the machine tool industry; success in the field of heavy, multi-purpose machine tools by British manufacturers was, as will be argued later, often obscured by failure in the lighter, single-purpose mass production machine tools which were newer, changing more quickly in design, and thus attracted most attention from technical commentators.

In spite of these deficiencies, it is possible to construct a picture of the British position in the international trade in machine tools. The first section of this chapter will therefore attempt to use this evidence to describe the chronology of the loss of British pre-eminence in machine tools.

1. <u>The chronology of the loss of British pre-eminence.</u>

To John Anderson, a leading British engineer, the beginnings of the loss of British pre-eminence in machine tools could be traced directly to the display of that pre-eminence at the Great Exhibition of 1851. As he

put it :

> "The effect of that display immediately told, not only upon the machinists of other countries, but likewise on our own of second and third degree, and by the arrival of the Paris exhibition of 1855 it was at once perceptible that a great change had taken place..." 2

The example set at that exhibition by Whitworth, Maudslay, Fairbairn, Sharp and the other British machine tool makers whose tools were displayed stimulated the emergence of native machine tool industries in France, Germany and the United States.[3] At the Paris exhibition of 1867 it was clear to both British and foreign observers that Britain no longer had a commanding lead. To Anderson, although the French and Germans displayed a large number of tools in 1867, they did not show evidence of technical originality, but the American machine tools were a more serious threat; in America, he wrote, the student of machine tools

> "will find something new; not only exquisite workmanship of the highest class, but new combinations even in connection with such a stereotyped article as a turning lathe or a planing machine, and without the loss of any of the essential points secured by English models." 4

An American observer in 1867 described the change :

> "The principal nations exhibiting were France, England, Russia and Austria. At the former exhibitions of London, Paris and 1862 the English were almost without rivals. On the present occasion they have but a small majority, and were vastly

2 Ibid, p. 702

3 A list of British exhibitors is given on pp. 199-201 of the Official Reports of the Juries on the Exhibition of 1851.

4 Anderson, loc.cit., p. [illegible].

> outnumbered by France and Prussia, while in point of novelty of form and excellence of workmanship [illegible] admitted to be on a par with any [illegible].' 5

The decline in the British lead in machine tools, as demonstrated in the reports on the International Exhibitions, continued during the next decade. Anderson, reporting on the Philadelphia Exhibition of 1876, was very critical of the British display, which

> 'contained so little of freshness, and was of so stereotyped a character, as to give encouragement to some of our foreign competitors to express openly in their printed reports, that we are losing our former leadership, and that it is owing to the American [illegible].' 6

To the American observer, at Vienna in 1873, [illegible] Thurston, the competition was severe, at least between America and Britain, "as it should be expected to be between what are really divisions of the same nation".[7] Both British and American observers agreed that the majority of the French and German tools displayed were copies, in general inferior, of British or American designs, although those were interested contexts; a French observer, perhaps from similar motives, commented that all the German and Austrian machine tools at Vienna were copies from tools made in Britain, the [illegible] and France.[8]

5 [illegible], [illegible] ed.) Reports of the United States Commissioners to the Universal Exposition, 1867 ([illegible]ton, 1870), [illegible] 272.

6 Reports on the Philadelphia International [illegible] of 1876. ([illegible] 1877, 1) Report on 'Machines and Tools [illegible] Metal, Wood and Stone', by John Anderson, p. [illegible].

7 Thurston, R.H. (ed.) Report of the United States Commissioners to the International Exhibition held at Vienna, 1873. ([illegible]ton 1874) Vol. III, 'Engineering' by R. H. Thurston, p. 211.

8 Pont[illegible], [illegible]. Machinery Exhibited [illegible] ([illegible]rio, 1874), p.128

After the Philadelphia exhibition of 1876, however, the criticisms of the British effort were few. There were, in fact, fewer comparisons of the type quoted above made in the Exhibition reports, and those that were made are not hostile to British. In 1873 the British observer commented that at Paris the British display was "highly satisfactory and maintained our reputation,.." [9] While, to the American observer the British tools were, "in point of workmanship,.... in advance of all others,...", although he also made the comment, slightly eccentric by this date, that British makers, unlike others, "were thoroughly well acquainted with the uses of the fundamental tool of the machine shop of today - the planing machine." [10] The American commissioners to the Paris Exhibition of 1889, although referring to the tributes to American mechanical skill "frequently expressed by both British and Continental engineers,..", reported that the "grandest single machine in this class at the Exposition was, without doubt, the large lathe just built for Schneider and Co." by Greenwood and Batley of Leeds.[11] In Brussels in 1910, the Times Engineering Supplement reported that "About half-a-dozen firms worthily upheld the reputation of British machine tools for excellence of workmanship and solidity of design." [12] and the same newspaper praised

9 Report of the British Commissioners of the Paris Universal Exhibition of 1878. (P.P. 1880, LXII, 1) p. 3.

10 Report of the U.S. commissioners to the Paris Exposition of 1878, (Exec. Documents, House of Representatives, 45th Congress, 3rd session, 1880) Vol. II, 'Report on Machinery, Apparatus and Machine Tools" by C.H. Porter, p. 1.

11 Report of the U.S. Commissioners to the Paris Exposition of 1889, (Misc. Docs. House of Representatives, 51st-52nd, 1890-93) Vol. 10, 1892, Part II, 'Machine Tools' by John H. Barr, pp 517, 552.

12 Engineering supplement to 'The Times'. Aug. 31, p.

the British effort even more highly in reports of the Olympia engineering exhibitions of 1910 and 1911. In 1910 they commented that "The exhibits... as a whole illustrate the reasons why many English makers are so successful in holding their own against foreign competitors in this department."[13] In 1912 the exhibition, "vividly illustrates the forward step which has been taken by British manufacturers within the last few years", the industry having organised itself, begun to specialise, reduced its costs, adhered to delivery dates, and fought off the danger that it would succumb to foreign competition."[14]

The evidence of the reports on the major exhibitions of the period from 1850 to 1914 thus suggests a chronology of British competitiveness in the international market in machine tools in which the British lead is eroded between 1850 and, approximately, 1870 to 1890. From this time commentators seem to cease to comment on Britain's lost leadership, and instead concentrate on the advantages of particular British tools or types of tools, thus treating Britain as one among equal competitors. This is particularly true in relation to American competition; British tools are still usually referred to, at least by British and American commentators, as being superior to the general run of tools from European countries, largely France, Germany, Switzerland, Belgium and Austria.

13 Engineering supplement to 'The Times', Dec. 14, 1910.
14 Engineering supplement to 'The Times', Oct. 16, 1912.

The evidence of the miscellaneous other commentators on the relative status of Britain in the international production of machine tools confirms this chronology, and also provide information on the competition between Britain and other countries in the period after the erosion of the British lead. In the earlier period, before the 1870s, although competition is fierce, the British tools are in general described as the best in the world. In 1868 a correspondent of the 'Scientific American', for instance, wrote that although American tools had "the greatest amount of originality,... it is not always easy to assert that their designs are decided improvements on the usual British types of machines", and he concluded that, "If there is any one branch of engineering in which the English particularly excel, it is in the construction of machine tools..."[15] At the same time, it was said in a series of articles in the 'Standard' that in machine tools "The Belgians challenge us (Britain) for cheapness; we challenge them and all the world for quality".[16] while "The reputation of England as the first machinist in the world should not be permitted to be lowered. The Prussians and Saxons are the best of our competitors, but they do not equal England as represented by her best tool-makers."[17] An American writer, in general hostile to British engineering, Charles B. Porter, thought that at least in 1870, British tool-making was superior :

15 Mr. Slade, Special correspondent of the 'Scientific American' quoted in A.S. Brown, ed. 'An Import... Facts and Figures for 1868'(Lon. 1868), p. 299.

16 An article in the 'Standard' of London, quoted in ... Brown, op.cit., p. 299.

17 Brown ..., op.cit., p. 302.

> "At that time, toolmaking in this country (U.S.A.) which has since become so magnificently developed, was in many important respects in a primitive condition, and I proposed to introduce into my shop every best tool and method, adapted to my requirements, that I could find in England.... I found also the remarkable fact that I could obtain these tools, duty and freight paid, decidedly cheaper than corresponding inferior tools could then be got from American makers." 18

In the later part of the century, the competition of American and German machine tool producers, both in the British home market and abroad, became much more severe. This was particularly true in the field of light mass-production tools, suitable for the sewing machine and cycle industries. According to a Mr. Henry Webb, addressing the Manchester Association of Engineers in 1893, "The bulk of the tools in the cycle works at Coventry came from America", since the American manufacturers excelled the British in the manufacture of automatic screwing machines and turret lathes, suitable for cycle manufacture.[19] Bertold Buxbaum, while commenting that "Um das Jahr 1850 begannen die Staaten von New England ihre Werkzeugmaschinen auch nach England auszufuhren", dated the main penetration of the British market to the development of the turret lathe between 1890 and 1900.[20] Further impetus to the American sales of machine tools in Britain came it was said as a result of the British engineering strike of 1897,[21] coinciding with the

18 Porter, Charles T. 'Reminiscences of Life as an Engineer' (New York and London : 1903) p. 169.

19 Webb, Henry 'On Rich and American Methods in the Engineering and Iron Trades' Engineer, Lon. Vol.35, June 11, 1893, p. [illegible].

20 Buxbaum, Bertold 'Der amerikanische Werkzeugmaschinen- und Werkzeugbau im 19 Jahrhundert'. Beiträge zur [illegible] Technik, Berlin, Vol. [illegible], (Year illegible) p. 123, 124.

21 Cox, Harold 'Labour Industrial [illegible]' (Lon. 1905) p. [illegible].

bicycle boom and [illegible] a domestic slump in the United States in 1896-7.[22] These statements give the impression of a sudden penetration of the market, but one of the major importers of American machine tools to Britain, Charles Churchill, wrote, on a number of occasions, that the growth had been slow and steady :

> "The introduction of American machinery has not been simply a matter of two or three years. It has [illegible] a steadily growing demand [illegible] years [illegible] was boomed a little through the bicycle [illegible], but the present time shows every evidence that [illegible]ade in American tools throughout Great Britain will steadily increase in the future." [23]

He repeated in 1902 that :

> "As we look back upon the work now we see that steady progress has been made; a curious feature of the growth of the business being that, if we disregard the 'hump' in the curve of our progress caused by the bicycle boom of 1896-7, the curve is generally regular and steadily upward." [24]

On the other hand, it is certainly true that the 'hump' was spectacular. The 'American Machinist' reported in January 1895 that Churchill's sales were up by 20% over 1893-4, "at a time when the general trade in Great Britain has been extremely quiet" [25] in 1896 a [illegible] of 230% was declared on the share capital of £5,500,[26] and in

22 Unsigned article in the '[illegible]achinist', American edition, July 13, 1899, vol. [illegible], p. 647.

23 Letter from Charles Churchill, '[illegible]achinist', American edition, March 30, 1899, Vol. 22, p. 265.

24 Churchill, Charles "The American Tool Business in [illegible] Britain", [illegible]achinist, American edition, Nov. 7, 1902, vol. 25, p. 1021.

25 '[illegible]achinist', Feb 7, 1895, vol. 18, [illegible].

26 Unsigned article "Charles Churchill 1835-1919", [illegible] and Engineering Craftsman, March 1965, vol. 25, no. 5, p. 197.

1897 the recent growth of the firm was described as '[illegible]', sales in a recent period of six months in London and Birmingham having been worth [illegible].[27]

Whether the growth of demand for American tools was slow and steady, or the result of a chance conjunction of the bicycle boom and the engineers' strike in 1896-7, there can be little doubt but that American tools were well established in Britain and in other European countries by the beginning of the twentieth century, and that in many cases they had supplanted British tools. In 1898 the President of a large American machine tool firm referred to the large exports of machine tools in recent years to Germany, heavy sales to the French government, and to Belgium.[28] . . Carden, the American who toured European engineering works on behalf of the American government in [illegible], comments several times that only the older tools in various factories are of British origin, the more modern having been bought in America, or, in one or two cases, from the native machine tool industry or from Germany.[29]

There are however some signs that the effects of American competition, and the backwardness of the British industry, were over-rated by contemporaries.

27 Miller, Ralph J. 'American and other Machines Abroad' American Machinist, American edition, May 20, 1897, vol. 20, p. 371.

28 Dana, [illegible] 'American Machine Trade in [illegible]', American Machinist, European edition, Jan [illegible], [illegible]. Dana was President of the Bigelow and Dana Tool [illegible].

29 Carden, [illegible]. 'The [illegible]-tool trade in...' (Washington 1909-10) Belgium, p. [illegible], Switzerland, p.174, Austria-Hungary, p. [illegible], 7.

In the period after 1900 there was undoubtedly a revival in the British machine tool industry. Thus Mr. Shadwell, writing in 1903, admitted that ...

> "... in the modern development of machine tools... British makers have not played a prominent part... Our people had been asleep for some time... They had got into a comfortable groove and had stayed there",

but he thought that there were now some signs of ... In 1906 a British engineer argued that the difference between British and American practice was not very great; "In most respects an up-to-date American machine shop does not differ greatly from an English one engaged on similar work."[31] And the United States Consul in Birmingham reported in 1907:

> "the great headway made by British makers of machine tools... the long delay of American manufacturers in filling orders is leading British engineers to buy their tools elsewhere, and... British tool-makers are seizing the opportunity to make and push tools made on American models."[32]

Carden commented on a number of British firms who offered strong competition to American and other makers. Foremost was Alfred Herbert of Coventry, of whom Carden said that "there is no denying that the Herbert machine tools, and in particular the turret lathe of this firm, are strong competitors of the best work turned out from American shops."[33]

30 Shadwell, Mr. ..., Engineering Supplement to The Times, Feb. 19, 1903.

31 Foster, Frank, Engineering in the United States (Manchester, 1906), p.14.

32 United States Consular Report, quoted in the Engineering Supplement to The Times, Jan. 16, 1907, ...

33 Carden, ... 'The ... Trade in ...', p.25.

but he also raised L ng's an' Darling and ellio.s.[34] On the other h nd, in spite of this revival, it is cle r that there continued to be considerable im orts of machine tools into rit in; as the alfo r Committee of 1918 reported :

> "Throughout the evi'ence we were confronted with large purch ses before the war from the nited tates of m chine tools, in which their manufacturers specialised, such as automatics, grinding, milling and drilling machines, r ses, lathes and gear cutting machines, ea ers instruments and other small engineers tools, ilot, as , special tools only were brou t from .'[35]

Contemporary com ent on the position of ritain in the international market in machine tools is certainly confused, and is blamed by the various st d- oi ts of the . It is however possible to dis ., so fa , a certain chronology in the decline of British re-eminence, which had been demonstrated in 1851. It would appear that rench, German and merican tool- akers began to compete seriously with the British makers in the 1860s and that by the 1870s the ritish lead, at least in technical terms, had been erode . The major penetration of the European market , including ritain, by the nited tates, can be dated in the middle of the 1890s, at which time the ritish makers were not offering any serious competition to this invasion of their rket. ly, during the period 1900 to the first worl war there were signs of a British re ival, in both the technical and the commercial fiel , ut the revival was not s fficient

34 ar'on, ., op. c., pp. 23,24 .

35 Balfour Co ittee, Re ort on ngineering trade after the ar. (on , 1918).

to win back fully the position which Britain had earlier held.

This chronology, vague as it necessarily is, especially in the imprecision of the distinction between technical and commercial superiority, which is particularly important, can only be checked by statistical evidence on the actual volume of machine tools entering international trade during this period. Unfortunately, as has already been made clear, the sources for such evidence are very poor. The British trade statistics do not distinguish machine tools from other engineering products, while the American trade statistics do not do so until after 1918. The German and the Austro-Hungarian statistics, although they do distinguish machine tools from other engineering products, do not provide information on the country of origin of the tools, but record imports by the frontier post through which they entered the country; there is therefore no way of distinguishing countries of origin, since an import through, for instance, Hamburg, might well have come from either Britain or the United States. The Belgian trade statistics do distinguish imports by country of origin, but make no distinction until very late in the period between machine tools and

small tools. The only major industrial country in this period which did distinguish imports of machine tools from other products, and which listed imports by country of origin, was France, and the French trade statistics are therefore used below. As to private sources, the only business records available are those of two American manufacturers, Brown and Sharpe and the Pratt and Whitney Company, and of one British manufacturer, Greenwood and Batley.

The French trade statistics,[36] in so far as they relate to machine tools, have a number of deficiencies. From 1865, the first year in which machine tools are distinguished from other machinery, until 1891, machine tools are listed in a category headed 'Machines-outils et machines non denommees'; there is also a separate category of 'Machines non denommees', and the distinction between these two categories is not made clear in the printed returns. From 1891 the second category of 'Machines non denommees' disappears; machine tools are still listed under 'Machines-outils et machines non denommees'. From 1892 to 1914 a separate category of 'Machines-outils' is used, and a category of 'Mecanique generale' is introduced. The first problem in using the statistics is therefore to estimate how seriously the changes in categories, and the possible inclusion of an indefinite amount of miscellaneous machinery in the machine tool category from 1865 to 1891, affects their value. It is clear that the other categories under the general heading of this section

36 Tableau general du commerce de la France avec ses colonies et les puissances etrangeres, prepared by the Direction des Douanes et Droits Reunis of the French Government, and published annually.

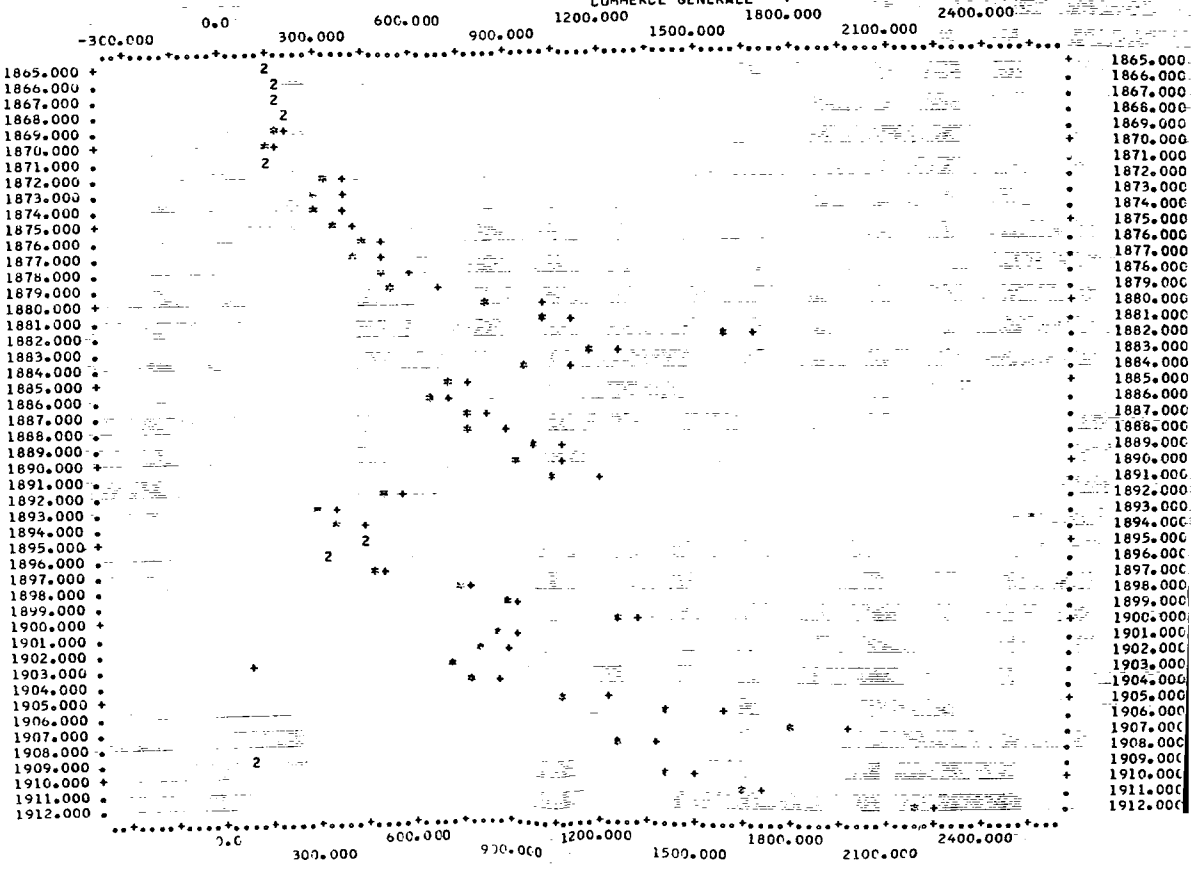
of the Trade statistics, ' achines autre qu'a vap..r' were designed to disti guish separately as many types of machinery as possible, so that the number of possible ' achines non denom ees', the residual cate ory, is likely to be s ll.[37]

Secondly, it is possible to examine the statistics themselves to see whether there is any marked change or break in trend in either 1881 or 1892, which might be the result of a change in categories rather than a real change in imports of achine tools. As graph , 1, French imports of machine tools (or categories including machine tools) shows, there is no sign of a change in trend between 1880 and 1881; machine-tool imports rise, as would be expected if all miscellaneous machinery was 'in', but the trend does not alter . For 1892 the situation is somewhat different; there is a marked change apparent in the statistics, imports apparently dropping by approximately . It seems likely that this was in fact at least partially the result of separating the 'Machines-outils' category fro that for ' echnique generale', and that, when absolute

37 For instance, the c to ories enumerated separately under the general heading of ' achines autre qu'a va eur' are : 'pour la filature; a nettoyer et ouvrir la laine, le li , le coton et autres matieres textiles; pour le tissage; cardes non garnies; metiers à tulle; a fabriquer le papier; a imprimer; pour l'agriculture; tenders de machines locomotives; chaudieres decouverte, poeles et calorifere en tole ou en fonte et tole; appareils à sucre, à distiller, de chauffage, en cuivre; machines à coudre; machines-outils et machines non denom ees".
These categories changed slightly from year to year, but the number remained approximately the same.

GRAPH 4,1

FRENCH IMPORTS OF MACHINE TOOLS COMMERCE SPECIALE *
COMMERCE GENERALE +



import figures are being considered, it is wise to regard the series as being broken at that point, and to remember that the figures certainly for 1831 to 1891 contain machinery other than machine tools. It is however clear from graph 4, [illegible] percentages of total imports from the major countries of origin, that these market shares do not alter in any period direction in either 1831 or 1892; it seems therefore reasonable to regard these shares, which are in fact the main point of interest, as relatively.

A second difficulty with the statistics, which relates only to the period before 1870, is that up to that date the item imported was attributed to its true country of ultimate origin only if it reached France by land; if it came by sea then the country under which it was listed was that at which the ship bringing it had last called. In and from 1870, however, the true country of origin was asked for in both cases. It is possible that some imports from the United States before 1870 might be under-enumerated because of this, but as can be seen from the graphs, American imports remained very small long after 1870, so that any under-enumeration cannot seriously affect any conclusions drawn from the [illegible] data.

Thirdly, the statistics distinguish two categories of imports, commerce speciale and commerce [illegible].[38]

38 The exact definitions of these two types of trade differed from year to year, in form [illegible] not in substance. As an example, the definitions given in 1871 were: "A l'importation, le Commerce general se compose de toutes les marchandises qui arrivent de l'etranger, de nos colonies et de la grande [illegible], par terre ou par mer, tant pour la consommation que pour l'entrepot, le transit, la reexportation ou les admissions temporaires. Le commerce special comprend les marchandises qui sont laissees a la disposition des importateurs, c'est a dire la totalite des marchandises exemptes de droit, et,

HEALTH SCIENCES COMPUTING FACILITY, UCLA

GRAPH 4.2

BELGIUM =

PLOT OF PERCENTAGES OF TOTAL FRENCH NET IMPORTS OF MACHINE TOOLS COMING FROM EACH OF SIX MAJOR COUNTRIES

0.075 0.225 0.375 0.525 0.675

0.150 0.300 0.450 0.600

1910.999

1905.999

1900.999

1895.999

1890.999

1885.999

1880.999

1875.999

1870.999

1865.999

Broadly, commerce generale was total imports into France, including items that would subsequently be re-exported, or which were transhipped in French ports, while commerce speciale included all items destined for use or consumption in France itself. Commerce speciale was therefore imports net of re-exports.

Fourthly, the imports were recorded by volume and value, but only volume figures are given for individual countries. Since no information is available on the weight-price ratios for imports from different countries, it is impossible to know how seriously this method of recording affects any attempt to look at the value of international trade in machine tools. For instance, if American tools were in general more expensive per tonne than British tools, the French trade statistics would under-rate the relative amount of American machine tool exports to France, as compared with British tools. The real value per tonne of machine tools was probably rising over the period from 1865 to 1914, but the reasons for this are not entirely clear, and it is impossible to know whether the trends in price per unit of weight differed markedly from country to country.

Within these deficiencies, which should be borne in mind in interpreting the statistics given below, it is possible to examine the French trade returns to see whether they support the chronology of the loss of British pre-eminence in this field which has been suggested above on the basis of the qualitative evidence.

30 continued:
"quand il s'agit de marchandises tarifees, les quantities qui ont ete soumises aux droits."

Graph 4, 2, shows the proportions of total French imports of machine tools net of re-exports originating in the six countries from which imports largely originate. (Machine-tools is used here and hereafter as a shorthand for the various categories including machine-tools which were discussed above). Imports from other countries were quantitively insignificant compared with those from England, Germany, U.S.A., Belgium, Italy and Switzerland, which are those graphed. The major trend which can at once be observed is the decline of British exports to France, from a peak of 60.5% of French imports in 1865 to a low point of 7.1% in 1899. This decline accords with the evidence given by contemporary observers, and it is clear that the chronology of the decline shown in graph 4, 2, also accords with that gathered from contemporary evidence. Britain is still in a strong position in 1865, but is losing her predominance, in the face of competition from, in particular, Germany and Belgium. The British share of the market is first exceeded by Germany in 1873, although from 1874 to 1882 Britain regains her lead, to lose it to Belgium in 1883. From this period it is clear that the British pre-eminence has been lost, and that, in the competition for exports to France, Germany, Belgium and Britain rank together, each with approximately 30% of the market.

The major change in this pattern of parity between Britain, Belgium and Germany in the French market can be dated to the 1890s, and particularly to the rise in imports from the United States in 1897, 1898 and 1899. This rise can be ascribed partially to the bicycle boom, which

affected France as well as Britain in this period, but it is also clear that at this period the United States effectively captured approximately half the share of the French market previously held by [illegible]. Germany from the same period captured an increased share, perhaps at the expence of Belgium, whose share dropped from 30% in 1895 to 4% in [illegible]. (It is of course impossible to know whether in fact the shares of Belgium and Britain were divided in exactly this way). There is no sign thereafter of any British recovery in the field of French imports, but it is interesting to observe that, after the initial loss of approximately half her share in the 1890s, Britain retains a portion, at a lower level, with the American imports; British sales to France exceed those of the United States in 1900, 1901, 1902, 1907, 1908, 1910 and 1912, and equal them in 1909 and 1911.

The most surprising feature of the French statistics on the import of machine tools, when they are considered in the light of contemporary comment, is the long delay before the effects are felt of American technical excellence in the design of machine tools. It will be recalled that it was in 1867 that John Anderson described American machine tools as a more serious threat to Britain than those of France and Germany, and in 1876 that he said that "we are losing our former leadership, and that it is passing to the Americans".[39] In the light of these and

39 See p.148 above, footnote .

similar comments, it seems surprising that the American technical advantage was not translated into commercial success in France until 1896 and [illegible], though there is a short spurt, in which 7% of the market was achieved, in the period from 1886 to 1891. In other words, the American penetration of the French market was delayed for anything up to twenty years from the time when a British observer regarded American tools as superior to those of any European competitor; these same European competitors were, at the same time, selling vastly more machine tools to France than was the United States.

Confirmation of the relatively late penetration of the European market by American manufacturers of machine tools can be obtained from the records of two American machine tool makers. Information on the Brown and Sharpe Company's sales to Europe were obtained from the company records, (as far as sales to Britain were concerned), and from Professor MacDougall's article on 'Machine Tool Output; 1861-1910', which also gave information on shipments by the Bullard Company.[40]

The firm of Brown and Sharpe was founded in 1833, but began to manufacture machine tools only during the Civil War.[41] Milling machines and grinding machines were the main pre-occupation of the firm, but they also sold gear-cutting machines, screw machines, lathes, polishing and

40 MacDougall, A. 'Machine Tool Output, 1861-1910' [illegible], 'Employment and Productivity in the United States after 1800', Studies in Income and Wealth, [illegible] (New York, 1966).

41 Roberts, [illegible], History of the British Machine, (Cambridge, Mass., 1958), p. 59-60. Holt, H. [illegible], Tools for the Job, (London, 1965), p. 171.

finishing machines, screw-slotting machines, chucking machines and tapping machines, as well as special machines for armaments [illegible].[42] The firm pioneered the production of a number of new machine tools, principally milling and grinding machines. Brown's universal milling machine, invented in 1861, is described by Woodbury as 'epoch-making', and as embodying '[nearly] all the basic features of milling machines to this day',[43] while his universal grinding machine, invented in 1875, was similarly the prototype for the modern grinding machine which is 'still basically the universal grinding machine as Joseph R. Brown conceived it'.[44] The Brown and Sharpe Company were therefore in the forefront of the technical development of the two major innovations in machine tool design which took place between 1850 and 1914, and they were able to sell these prototype machines, and these of improved design which they later produced, both at home and abroad.[45] While Brown and Sharpe concentrated on the light, mass-production machine tool which were considered by many observers to be typical of American machine tool production, the Bullard Company, established as the Bridgeport Machine Tool Company in 1880, concentrated on 'the larger type of production machine tool', and sold many tools to railway and other heavy engineering workshops.[46]

42 Information from the sales records of the Brown and Sharpe Manufacturing Company, and from MacDougall, [illegible], p. [illegible].

43 Woodbury, [illegible], A History of the Milling Machine (Cambridge, Mass., 1960), p. [illegible].

44 Woodbury, [illegible], A History of the Grinding Machine (Cambridge, Mass., 1959), p. [illegible].

45 Woodbury, "Grinding Machine", [illegible], and Sales Records of Brown and Sharpe Manufacturing Company.

46 MacDougall, [illegible], pp. 504, 5[illegible].

Between them the two firms thus span the range of machine tool production during this period.

It is therefore interesting to note that, in the case of both of these firms, sales of machine tools to European, or indeed extra-American customers, were very small before 1895. Table4, 1, reprinted from Professor MacDougall's article, shows foreign shipments of machine tools by the two companies. As MacDougall makes clear, foreign sales were an important part of the output of the companies, making up more than 10% of sales by Brown and Sharpe from 1865 onwards. On the other hand, absolute numbers sold, particularly to Europe, were very small before 1895, when there is a very obvious change in trend. Brown and Sharpe sold 1250 machine tools to North-West Europe in the thirty-five years up to 1894, and 2,560 in the following five years from 1895-1899. The contrast is even clearer with Bullard shipments, 27 between 1881 and 1894, 446 between 1895 and 1900.[47] The more detailed breakdown of the British sales allows the change to be dated even more precisely to 1896. Only 74 milling machines worth 51,215 dollars were sold by Brown and Sharpe to British customers between 1865 and 1895, but in 1896 alone they sold 61 milling machines worth 42,000, and in 1897 and 1898 a total of 212 machines worth 31[illegible],700. A similar expansion took place in sales of grinding machines and gear-cutting machines. Yearly total sales of machine tools to Britain by Brown and Sharpe did not rise above 15,000 dollars in any year

47 MacDougall, [illegible], p. 507, table 1.

Foreign shipments of machine tools, by region of destination, quinquennial, 1861-1909. (Number of machines)

Period	North-West Europe	South Europe	Canada	Russia & East Europe	Central & South America	Australia	As Afr
1861-64	0	0	0	0	0	0	0
1865-69	27	3	16	1	0	0	0
1870-74	60	10	34	5	0	0	0
1875-79	55	0	5	0	3	0	0
1880-84	84	0	29	2	7	1	2
1885-89	633	0	13	2	5	2	0
1890-94	431	6	25	38	8	7	7
1895-99	2560	43	39	257	16	7	18
1900-04	2349	49	140	127	18	2	336
% distribution of totals	82.9	1.5	[illegible]	[illegible]	0.8	.	[illegible]

BROWN and [illegible].

1861-[illegible]	7	0	1	0	1	0	0
1865-[illegible]	13	0	0	0	0	0	0
1890-94	7	0	4	0	0	0	0
1895-[illegible]	446	0	2	8	1	0	0
1900-[illegible]	394	3	30	1	1	0	2
1905-09	341	20	29	9	4	1	9
% distribution of totals	90.6	1.7	[illegible]	1.3	0.5	0.0	[illegible]

BULLARD.

TABLE 4.1 Foreign shipments by two leading United States machine tool makers.
Source: D. MacDougall, 'Machine Tool Output, 1861-1910', Output, Employment and Productivity in the United States since 1800. (N.B.E.R., Columbia U.P., 1966) p.507.

until 1895, and did not fall below that level again until 1917, having reached a peak of $203,643, in [illegible].[48] As MacDougall shows, this pattern of a rapid expansion of sales after 1895 was paralleled in sales by Brown and Sharpe to all major European countries, with the exception of France, where sales peaked from 7 machines in 1880-1884 to 352 machines in 1885-1889, and then fell to 60 machines in the next quinqueenium, before rising again with all other countries after 1895. As MacDougall says, this peak can be explained by heavy sales to French Government arsenals, which took nearly 200 tools between 1886 and 1888.[49]

In the case of these companies, therefore, the same paradox emerges as in the more general consideration of contemporary comment and French imports of machine tools. Both companies were innovators in the machine tool field - Bullard produced 'a significant contribution to the technical progress of the machine tool art with the invention of a small boring mill' in 1[illegible],[50] and the technical advances made by Brown and Sharpe have been [illegible]. The machine tools made by Brown and Sharpe were certainly well known to European customers from 1867, when their tools were exhibited at the Paris Exhibition, and they produced a French catalogue in 1867, and a German catalogue in 18[illegible].[51] Yet both Brown and Sharpe

48 Sales records of Brown and [illegible].

49 MacDougall, [illegible]. loc.cit., p. 508

50 MacDougall, [illegible]. loc.cit., p. 501

51 MacDougall, [illegible]. loc.cit., p. 503

and Bullard, and American toolmakers in general, as can be seen from the French trade statistics, failed to make a significant impact on the extra-American market for machine tools before 1893-7.

In the remaining sections of this chapter, the explanation for this paradox, and for the general chronology of the machine tool trade, will be sought, with a particular emphasis on the role of British machine tool builders and the competition which they faced from the United States. Possible differences in commercial methods, and possible effects of tariffs and other artificial barriers to trade, will firstly be considered, and finally other hypotheses will be explored.

The British sales effort in international markets.

During the first part of the period 1850 to 1914 British exporters of machine tools seem to have been fortunate in a lack of effective competition from any other country; British tools were superior in every way, and often, as the quotation from Porter given above demonstrates, cheaper than foreign-produced tools even when transport costs were taken into account. With the advent of foreign competition, both commercially and technically, it was necessary for British machine tool makers to seek more actively to make sales abroad, and to cease to rely on the maxim, so often quoted by early tool-makers, that 'a good tool sells itself'. British machine tool-makers were faced with a number of choices when they sought to sell their tools in foreign countries; they had to choose whether to sell direct or through

agents, either in Britain or in the export market, whether to produce catalogues in foreign languages, whether to exhibit at international exhibitions in the hope of attracting interest or orders, whether to employ salesmen, and they had to decide on the payment and credit terms which they were prepared to offer foreign customers. It is apparent from the scattered evidence that is available that all these choices were taken up, at one time or another, by British companies; they will therefore be examined in an effort to understand their advantages and disadvantages, and the effect which they had on the British ability to sell machine tools in the international market.

One of the most obvious methods of making new machine tools known to a wide audience was to exhibit them at one of the many international exhibitions, held at various times in most of the industrialised countries of Europe and America. It therefore often was a subject of criticism of British machine tool makers at the time that many tool makers did not exhibit at the exhibitions, and that Britain was under-represented compared to her competitors. In Paris in 1867 the British exhibits were described as 'but a small display' by the American commissioner, while John Anderson commented that Britain was 'lothargic...and', but for the circumstance that a few of the best makers have come forward, Great Britain would have been unrepresented'.[52] Anderson's report on the Vienna Exhibition of 1873 commented that ' any of our best

52 Report of the U.S. Commissioner to the Paris Universal Exposition, 1867, ed. . . Blake, (Washington, 1), p.173. Report on the Exhibition of 1867 (P. . 1867-8, XXX, Pt. I), p. .

houses were not represented at Vienna by even so much as a single specimen: hence the general poverty',[53] while the technical reports on the same exhibition by ... Daw and James Dredge were prefaced by the comment that :

> "Altogether the collection of machine tools in the British department but very poorly represented the progress of this branch of engineering in England, and to all who were familiar with the numerous admirable special tools to be found in our leading engineering factories, the British exhibits of this class at Vienna could not fail to be most disappointing'.[54]

This catalogue of British failure was continued at a number of other exhibitions. The International Judges at the Philadelphia Exhibition of 1876 regretted that :

> "Great Britain, which stands so high in this class of machinery, was not better represented. The exhibit of that country was conspicuous by the absence of all the well known names with which the world has been familiar.'[55]

At Paris in 1889 most of the leading British engineering manufacturers were not represented, and those that were were criticised by the French official report for failure to show off their exhibits :

> "L'impression de monotonie que nous ressentions tout à l'heure s'est accrue d'une maniere sensible. Tous ces employes, hommes ou femmes, assis au debout derriere leurs utrines, semblent dormir les yeux ouverts. Il y a la comme une vie automatique en suspens, qui se reveille de temps a autre par mouvements saccades.' [56]

53 Report of the British Commissioners to the Vienna Exhibition of 1873, (P.P.1874, LXXIII, Pts.I & II), p.12.

54 Technical Reports on the Vienna Exhibition of 1873, by ... Daw and James Dredge (P.P.1874, LXXIII, Pt.II), p.771.

55 Reports of the Philadelphia International Exhibition of 1876 (P.P.1877, LXXVI), Vol.III, p.732, reprinting the report of the International Jury.

56 Official report on the Paris Exhibition of 1889. (Paris, 1890), p.102.

In the report on the Paris exhibition of 1900 the British juror commented on the small number of British firms exhibiting, and listed six firms as 'conspicuous by their absence'.[57] Before the St. Louis exhibition of 1904 the British government tried to encourage British firms to exhibit, but :

> "The replies showed that no engineering firms were prepared to take part in the exhibition, even to the extent of furnishing engines or dynamos for the motive power plant, for which the Administration of the Exhibition were willing to pay all expenses."[58]

while the report of the British Commissioners on the exhibitions at Brussels, Rome and Turin in 1910 and 1911 commented that the machine tool section contained the work of only seven British firms :

> "whose products were of high excellence, design, build and finish, comparing very favourably with those of foreign competitors, but not sufficiently numerous as compared with the latter to give an adequate idea of the enormous importance and leading position of the machine-tool industry in Great Britain."[59]

Proof that the failure of British manufacturers to exhibit at these exhibitions was the result of lethargy or failure of enterprise would throw considerable light on the failure of British machine tool makers to maintain their predominant position. It is clear, however, that

57 Report of Royal Commission on the Paris Exhibition of 1900 (P.P.1901, XXXV), Report by C.P. Burton on Machine Tools, p.[illegible].

58 Report of the British Commissioners to the Exhibition at St. Louis, 1904. (P.P.1905, LIV), p.459.

59 Report of the British Commissioners on the Exhibition at Brussels, Rome, 1910 and 1911 (P.P.1912-13, XXII), p.2[illegible].

British machine tool makers could have sound commercial reasons for failing to send their tools to exhibitions, even if they were taking a [illegible] view of commercial considerations. The reasons given by the makers for dislike of international exhibitions were that exhibiting was expensive, that it did not produce an adequate return in terms of additional machines sold, and that it diverted attention from manufacture of machines which had already been ordered. In 1867 an observer admitted that one of the reasons for the poor British display was that 'the majority of houses were tired of the unremunerative expence of former exhibitions'.[60] Both the British and the foreign observers at Vienna in 1873 recognised that a rise in demand for machine tools made it difficult for British makers to spare the time to make tools for exhibition,[61] and much later in the period, the British commissioners at Brussels, Rome and Turin, discussing the failure of British firms to exhibit, said that the firms relied on their long-established reputations to sell their tools, and saw little advantage and much expense in sending machines to exhibitions.[62]

It is difficult to know how well-founded these objections or excuses were, especially because, even when detailed sales records are available, sales as a result

60 Report on the Paris Exhibition of 1867, op.cit., p.70.

61 Technical Report on the Vienna Exhibition of 1873, [illegible], p.[illegible] Reports of the [illegible] Commissioners to [illegible] 1873, (Washington 1874), [illegible]

62 [illegible] Commissioners to Brussels, Rome and Turin, [illegible], p.235.

of exhibitions cannot easily be distinguished from sales which would have been achieved anyway. Greenwood and Batley sent machine tools to the Melbourne Exhibition in 1880, but sold only ten machine-tools in Australia, in the next twenty years, one in 1886, eight in 1889, and one in 1899; it seems unlikely that any of those sales resulted from the exhibition. Although the firm did send machine tools to a number of exhibitions, the attitude of the firm was made clear in 1889, when the large engine lathe, praised by commentators, was sent to the Paris exhibition; the Minutes of the Board of Directors recorded that 'After a great deal of trouble and at considerable expense, the large lathe had been erected and was now working in the Paris exhibition, where it formed one of the chief [illegible].'[63] It was largely because of the Machine Tool and Engineering Association, formed in 1911, promised to control the number of exhibitions, that Greenwood and Batley joined the Association as a founder member, it being recorded in the Board Minutes that 'The object of the Association..(ie). to prevent the holding of a large number of Engineering Exhibitions, and to promote the sale of Machine Tools of English manufacture;' the order in which the objects are stated is surely significant.[64] It was apparently felt that a large amount of effort and expense was being wasted by the holding of a large number of exhibitions, and the new association undertook to organise national exhibitions to be held every three years, the first being that held at Olympia in 1912.

63 Greenwood and Batley Ltd., Board Minutes, July [illegible], [illegible].

64 Greenwood and Batley Ltd., Board minutes [illegible]. The Machine Tool and Engineering Association became the Machine Tool Trades Association, after the [illegible].

The attitude of Greenwood and Batley, and the other British firms, is understandable if it is remembered that the expense of sending a machine tool for exhibition could be considerable; in addition to the shipping costs of the tool itself, men would have to be sent with it to erect it and to work it as the exhibitions where the machinery was displayed in action, and, for firms where machinery was made only to order rather than to stock, the investment in a new machine could be entirely wasted if no customer could ultimately be found whose needs it suited. Even if the machine itself was sold, unless its display generated several further orders it was unlikely that a profit would be made on the venture as a whole, particularly in view of the profit margins under which firms like Greenwood and Batley were [illegible].[65] Thus, while it is possible to view the comments of manufacturers hostile to exhibitions as lethargy or lack of enterprise, it is possible that they had reasonable grounds for their scepticism; as has already been mentioned, Brown and Sharpe received high praise for their exhibit of a universal milling machine in Paris in 1867, but their total sales to France in the quinquennium 1865-1869 were only 12 machine tools of all types, and sales in the next quinquennium were only one machine.[66]

Perhaps a more fundamental choice which had to be made by British machine tool makers in this period was concerned with the methods of selling their [illegible], and

65 See below, ch. 5.

66 Jacobson-Hall, loc. cit., p. [illegible], table [illegible].

particularly whether the firm should sell its machines through agents or should attempt to sell direct, either through its own salesmen or through the dispatch of catalogues to potential customers. It is apparent that most British firms sold abroad by both methods; Greenwood and Batley, for instance, sold through 22 agents in foreign countries, as well as 77 at home, many of whom, from their names or the ultimate destination of the machinery, were acting as forwarding agents for foreign countries. Greenwood and Batley had agents in Belgium, Holland, France, Spain, Austria, Turkey, Russia, Canada, Italy and South Africa and in addition sold to Japanese and German agents who had offices in London. However, it is also clear that the directors of the firm spent long periods abroad in search of orders. On April 10, 1889 the Board were told that a director, George Greenwood, had been to Vienna to get an order for rifle barrel drilling machines from a Mr. Werndl, who was described as 'a gun-maker having large contracts with the Austrian and German governments', while the Chairman and one of the managers had been in Berlin to get an order for cartridge-making machinery. Later in the year one of the managers was reported to be returning from the Melbourne Exhibition by way of New Zealand, Java and Batavia in search of business, and in November George Greenwood was sent to Russia in search of contracts. Visits by directors to possible foreign customers in Hungary, Russia and other countries were also reported to the Board in later years.[67] Foreign purchasers were also encouraged to visit the factory in Leeds to discuss further purchases. Several British

67 Sales Records of Greenwood and Batley Ltd., and Board Minutes, April 10, 1889, July 12, 1889, Nov. 4, 1889, May 29, 1890, June 22, 1895.

firms also established offices abroad, sometimes acting as agents for other, non-competing British engineering firms. In 1874 Thomas Turton and Sons of Sheffield, who made machine tools amongst other machinery, had offices in Paris and New York.[68]

Alfred Herbert's also sold either directly or through foreign agents, a fact which H.B. Carden saw as related to their success :

> "I think it is safe to say that I found more Herbert machine tools on the Continent than from any other single English firm. There is no denying that the Herbert machine tools, and in particular the turret lathe of this firm, are strong competitors of the best work turned out from American shops. From several months observation in Europe I am convinced not only of the excellence of Herbert material but the efficiency of the commercial branch of this firm. It is noteworthy that Herbert is selling his own goods, and so far as I know his agents are under his direct control."[69]

Herbert's began by selling through agents :

> "We had made some contacts with Continental Cycle Manufacturers and this led us to explore the export field. Our first foreign agent was Adolf Jansen of Paris and Brussels, who at one time had an extensive connection among machine tool buyers. We then opened a branch of our own in Paris, which afterwards became Societe Anonyme Alfred Herbert, to be followed by similar enterprises in Belgium and Italy, and by a branch in Japan and then by subsidiary companies in India, Australia and the Argentine, and agencies in Berlin and Frankfurt. None of these business (sic) was manufacturing but only distributive; they widened the market for our products and encouraged the extension of the Coventry Works."[70]

68 Kelly and Co., Directory of Merchants, Manufacturers and Traders, 1874.

69 Carden, H.B. op.cit., (1909), p.225.

70 Herbert, Sir A.F. manuscript autobiography "Machine Chasers : Alfred Herbert Ltd."

Greenwood and Batley also set up a subsidiary company in Russia, although this had the object of protecting their large trade with Russia from the effects of anti-German Government measures against imports of machinery.[71]

The British machine tool trade with foreign countries was thus conducted, at least as far as the leading firms were concerned, through a variety of channels, suggesting that the companies were looking for business wherever and however they could get it. Again, as far as the leading firms were concerned, they were prepared to produce catalogues of their machine tools in the languages of the countries to which they hoped to sell. Greenwood and Batley produced a number of catalogues in French and German, Hulse's produced catalogues in Italian.[72] The British consul in Kharkov emphasised the importance of this in his report for 1909, adding that the giving of dimensions in metric terms was also essential, though it is doubtful how many firms took his advice.[73] It is of course impossible to know how the majority of British firms sold abroad, if they did so. There are a number of comments from British representatives abroad suggesting that methods were not very intense, and that British manufacturers did not exercise enough care in choosing foreign agents, sometimes choosing foreign firms who made competing machine tools:

> "The engineering and weaving industries (in Lyons) use British machine tools and looms, which are at present imported through local agents, many of whom are themselves constructors. A direct

71 Greenwood and Batley Board Minutes, May 24, 1 . The company was called the Komix Engineering Works Co.

72 Greenwood & Batley Ltd., records in Leeds Central Library for Prospectus, Machine Engineering Supplement, July 25 1907, p.256.

73 Board of Trade Journal, Vol. 1 , 191 , Annual Series . Report for 1909 of H. . Vice-Consul at Kharkov .

"trade in these goods might [illegible] be established between producer and [illegible]."[74]

A South African engineer commented that many South African agencies for British machinery were little better than ironmongers, and could give no service to potential customers.[75] It is also likely that a number of manufacturers shared the attitude of the firm of Dean, Smith and Grace of Keighley, who formed in 1[illegible], did not appoint their first traveller or salesman until 1[illegible], James Smith believing that 'no amount of office organisation can sell a bad machine, but good machines sell themselves.'[76]

In general, it would seem that the distinction between 'best practice' firms and the rest can be drawn with reference to commercial as well as to technical [illegible]. Herbert's seem to have been exceptional in the care which they [illegible]. Carden reported on their contacts with the Budapest Locomotive Works that:

> "The Editor (the Manager) told me that Herbert's engineers paid periodical visits to Budapest and personally instructed the locomotive workmen in the management of Herbert machines. An inspector from Coventry comes to Budapest at varied intervals, and personally takes notice of the running of the tools. The firm has gone further and induced the locomotive works authorities to send over to Coventry five of the leading workmen from the Budapest shops. These men will be instructed at Coventry and will undoubtedly learn much regarding the varied lines of machines as manufactured for modern-day requirements."[77]

74 Board of Trade Journal, May 26, 1910, Vol. LXI., p.[illegible]. Report for 1909 of H.M. Consul at [illegible].

75 [illegible], T., "Report on the Engineering Industries of the United States" (London: 1902), p.150.

76 "100 Years of Machine Tool Building", [illegible] Engineering Manufacture, June 19[illegible], p.[illegible],6, [illegible]. This is to appear to be taken from "[illegible] Tilford" by Edward Grierson (n.d.)

77 Carden, [illegible]., 1910. I, p.[illegible].

Greenwood and Batley also sent their workmen to superintend the erection of their plant in foreign factories, a director, George Greenwood, spending much of his time between 1860 and 1890 in charge of such work.[78] However, in general it seems likely that this type of after-sales service must have been confined to such sales as those of complete sets of factory equipment, and that the majority of firms did not undertake to do more than sell the machine. This discussion of the sales methods of British machine tool firms must therefore remain somewhat inconclusive. Some firms undoubtedly tried hard to sell their products abroad, others, at least if the image of the British manufacturer uninterested in exporting has any foundation, did not.

A further criticism which was levelled at British exporters in this period, as today, and which was regarded as one of the factors responsible for poor export performance, was that they were unwilling to grant generous credit terms, and demanded payment at an earlier stage in the progress of the work than did their competitors. In 1907 the Commercial Attache in Madrid commented that British firms often found it difficult to sell in Spain because of the requirements which they laid down for payment:

> "Theoretically the usual terms are one-third with order, one-third on leaving works, or on arrival, and the remaining one-third three months later; but, in practice, one would be fortunate to get normal terms of this kind, buyers liking to pay as much as possible from the profits derived from the machine purchased. The custom of long credits has been introduced within the last eight years by Continental firms, and it is now common to give one,

78 Memoir of George Greenwood, Transactions of the Institution of Civil Engineers, Vol. CXI, p.[illegible].

> "and sometimes up to two years. Under these circumstances it can be understood that 'cash with order' which is [illegible] by critical houses, is not very acceptable in Spain".[79]

The catalogues of British machine tool firms show the type of conditions which were laid down; Henry Berry of Leeds, who made hydraulic machine tools, listed the conditions of sale in their catalogue of [illegible]. Terms were cash in one month, less 2½% discount for cash. Foreign orders must be accompanied by a remittance of one third, and credit arranged in England. Packing cases were charged extra, but ⅔ was allowed for them if they were returned free and in good condition.[80] The 1905 catalogue of J. Butler and Co. of Halifax stipulated that references had to be given with first orders, and that in the case of foreign orders the order should either be accompanied by full payment or arrangements should be made to pay in England in representation of bills of lading or invoices.[81] Because of their large foreign business, Greenwood and Batley were obliged to accept payment in foreign currencies, although they made efforts to obtain at least some of the money in England. A large contract with the Russian government in 1890 was the subject of considerable discussion by the full Board of Directors, demonstrating the importance of terms of payment, to both customer and [illegible]. One of the Company's engineers, who had been sent to Russia to discuss the contract, had sent a telegram to

79 Board of Trade Journal, Nov. 28, 1907, Vol. [illegible], p. [illegible]. Report from the Commercial Attaché in [illegible].

80 Catalogue of Henry Berry and Co., Deposited in Leeds Central Library.

81 Catalogue of J. Butler and Co., in the possession of the firm.

enquire "whether the Company would accept payment in roubles instead of in pounds sterling. As the value of the rouble might fluctuate, any payment in roubles had been declined" the board was told. The conditions of the contract, as proposed by the Russians, were that 25% should be paid on signature of the contract, 40% on the machinery arriving in Russia, 15% on arrival at Tula (the site of the factory), and the last 20% four weeks after verification by the government engineer. The Russians also required a bank guarantee of repayment of the 25% deposit if the contract was not [illegible]. One of the directors reported that this condition was normal, adding that many foreign governments required caution money to be paid by contractors, rather than giving an advance. The Russians also wanted to pay to Greenwood and Batley's agents in Russia, but the Board decided to try to obtain payment in London.[82]

The importance of payment terms was of course that, particularly with the larger machine tools which might take over a year to build, to allow payment to be deferred until the completion of the order could have a serious effect on the liquidity of the producing firm. The Managing Directors of Greenwood and Batley, for instance, reported in 1902 that :

> "An order had been received from the Indian Government for Cartridge Machinery amounting to about £9,000 on which a good deal of money would be spent this year, whilst the profit would not come in until next year",[83]

but the company was forced to accept the order because

82 A. B. Board Minutes, Dec. 30, 1890.

83 A. B. Board Minutes, Jan 31, 1902.

of the depressed state of its order book. When in addition it was doubtful whether the customer would eventually pay for the tools, it can be seen why British firms were dubious about accepting foreign orders without substantial guarantees, but naturally the foreign customer was, in his turn, not anxious to tie up his capital in advance payments. All that can be said in conclusion on this point is that the difficulties in the way of easing terms of payment were increased by the low level of capital resources available to British machine tool firms. Had the firms been larger, and had larger reserves, it would have been possible for them to have given easier terms for payments, without, as Brookwood and Whitelaw were forced to do, incurring a large overdraft essentially to finance current expenditure.

There is no firm evidence, however, that the commercial methods of Britain's competitors in the field of machine tools differed very markedly from those of British manufacturers. Many of the American machine tools which were imported into Britain were sold through British firms acting as agents, the largest of these being Charles Churchill and Co. This firm was established in 1870, its founder having come over to England from the United States to instal machinery for covering wire with braid, an early stage in the manufacture of cables. He is said to have realised that there were a large number of machines available in the United States which were not known in this country, and to have seen the potential of importing these machines. It is clear that

machine tools were, at first, only one of the types of machinery which the company imported, others being agricultural implements, small tools, pumps and domestic machinery, but the company did act as the British agent for many of the leading American firms, principally Pratt and Whitney, Brown and Sharpe, Warner and Swasey and the Cincinnati Milling Machine Company.[35] In the passage quoted above, Charles Churchill himself argued that the growth in demand for machine tools was steady, but there is no doubt that the main expansion of the agency came after 1890, with the bicycle boom.[36] As a result of the expansion in demand, branch offices were set up in Birmingham, Glasgow, Manchester and Newcastle. It is however clear that the expansion in demand placed severe strains on the resources of the company. In 1888 a new partner had been introduced, and in the following year the partnership had been dissolved and a limited company formed, and in 1901 it was decided that the company would have to begin to build tools itself,

> "because of the large amount of capital that could become tied up in stocking American machines and slow delivery of certain types of machine tools."[37]

The decision to make grinding machines lost Churchill's agency for Brown and Sharpe, illustrating the difficulties of conflicts of interest between maker and agent. Another British firm, Sharp, Stewart and Co., of Manchester, made American tools designed by the Pollard Company

34 "Charles Churchill 1865-1965" [illegible] Manufacture, April 1965, Vol. 26, No. [illegible].

35 See above, p.153

36 "Charles Churchill, 1865-1965". [illegible]

37 "Charles Churchill, 1865-1965", [illegible], and "[illegible] Machine Tool [illegible]", [illegible].

under licence at least as early as 1875, unlike Churchill's who only began to do this in 1906,[88] and there were certainly other agents for American tools, among them Buck and Hickman, who were apparently in competition with [illegible] as agents for Brown and Sharpe and Pratt and [illegible]. It was said in 1897 that there were six agents for American machinery in London alone, and that "If a machine does not happen to be in stock, it can generally be delivered from America in from three weeks to a [illegible]."

In spite of this developed agency system for American machine tools in Britain, some dissatisfaction was expressed at the system as a whole, and it was argued that direct selling, or the establishment of branch factories, would be more satisfactory, although there was certainly no agreement on this among co[illegible]. The reasons for dissatisfaction with agencies were expressed in an article on "How Machine Tools are Sold"; although this appears to refer to sales within America, it probably reflects conditions abroad also. The writer, a Mr. Prevost, argued that :

> "The dealer, especially in the smaller cities, may have the agency for two or more manufacturers of the same kind of tools, and in that case one or the other manufacturer is sure to feel that he is not getting the amount of business he feels he is entitled to, and there is no doubt that the machine having the greatest number of talking points, or

88 Spon's Dictionary of Engineering (London[illegible]. 2329, 2338

89 Advertisement in "The Engineer", [illegible] 3, [illegible].

90 Reprint in [illegible] (American [illegible]. 1], Dec. 22, 1897, p.969., of an article by J. "Some Lessons of the Factory how", which originally appeared in [illegible].

> "the one that is advertised the most, or that is sold for the least money, is the one that is easiest to sell and has the greatest sale, for the salesman invariably takes the line of least resistance, and will sell the machine for which his customer shows a preference, and the average salesman is not slow to note and fall in with the views of the buyer. The very fact that machinery dealers are required to sell a great variety of tools prevents them or their salesmen from being familiar with all the working details and the advantages of certain parts of the different machines and it is no doubt true that there are many tools sold daily that are not the best for the kind of work for which they are purchased."[91]

In view of those difficulties, it was argued that American manufacturers should :

> "follow the methods of securing business abroad that they so successfully employ at home. I mean the establishment and maintenance of branch houses, managed by engineers who work solely in the interest of their own companies, understand advanced methods of manufacturing, and can take a practical part of their knowledge to the European [illegible]."[92]

The United States Consul in Birmingham also argued for this course in 1899, although for slightly different reasons :

> "The system adopted by one of the leading American firms of having a branch in this district where all tools are made for the English trade, is an excellent one, and should be employed by other American concerns building machines for similar [illegible]. Not only is there a saving of several weeks time in the delivery of a machine by having a place to fit it up here, but it also gives the opportunity to a possible customer to see machines in actual operation, and is the very best advertisement possible. As screw machines are usually fitted

91 "How Machine Tools are Sold", [illegible], p. 1,096, [illegible].

92 Orcutt, [illegible]. "Machine Tool Management in Europe and [illegible]. The Development of Trade under Competitive [illegible]", [illegible], No. 17, 1899, p.27.

> "with special tools made to fit models furnished by the customer, if is necessary, of course, where there is no branch ship here, to forward the models to the home shop in America, and the time elapsing until the machine is returned is necessarily of considerable length."[93]

It is clear that there was as little uniformity in selling practices, and as little agreement about correct methods, among American as among British machine tool makers. Some advocated agency agreements, some branch offices, some branch factories; to some the important factor was for a member of the firm to visit customers. Orcutt praises "representatives of more than twenty prominent machine tool makers who, for some time, have been visiting European countries once or twice a year."[94] but to Consul Halstead this same practice was to be deplored:

> 'They (representatives of American engineering firms) claim that the heads of even the big machinery concerns consider the export business as the place for the display of a little personal vanity, and take it under special care, with the result that, having multitudinous duties, much is neglected.'

Halstead, therefore from Orcutt's remark that:

> "In their methods of securing business, the American manufacturers of machinery have as little regard for worn customs as respect for old fashioned manners. The best of them advertise their wares in the leading technical journals in a manner which many European machine tool makers would not think

93 Report from H. M. Consul Halstead, Birmingham, No. 1399. Annual Series Reports, Vol. LX, 1891, p.25. This passage is a translation quotation from 'my informant', described as "one of the highest in both salesmen and expert mechanics I have met here".

94 Orcutt, W.H., loc. cit. p.270.

95 Halstead, loc.cit. p.25.

"it possible to do without sacrifice of their so-called 'respectability'"96

there is very little concrete evidence that American selling practises in the field of machine tools varied very greatly from those of British makers, or from those of other European countries. German and French producers of machine tools operated in very much the same way, through a mixture of agencies, direct selling, exhibiting their machinery, and the other methods which have been described.

American 'hard-sell' methods could have mixed results, as W.O. Riddell, a British machine engineer, described :

> "While Mr. Murdoch (his employer) was making a clean sweep of his machinery, many other engineers were installing new tools and there was a boom in the machine-tool trade. A number of salesmen from America arrived to push their wares. They were usually amusing fellows who had possibly been selling patent medicines in the past, for they made very extravagant claims. They sold quite a number of machines, many of which were quite unsuitable, and they did a lot of harm to their employers. I got the impression that American machines were rubbish, and it was several years before I discovered how good many of them really were.
> "Even Mr. Murdoch was impressed, and he sometimes sent for me to look at their catalogues, which were really a great advance on anything our more modest tool-makers published, and they were beautifully illustrated."97

It would therefore seem unlikely that, in the field of machine tools, Britain's early predominance was lost primarily as a result of inadequate methods of advertising

96 Orcutt, W.P.L. "Machine Shop Management in Europe and America. IV, Commercial Organisation and Sales Management" Engineering Magazine, Vol. 17, 1899, p.17.

97 Riddell, W.O. The Thankless Years. (London and Glasgow, 1948) p.196. These incidents apparently occured around 1900.

or selling the tools. It was perhaps short-sighted to refuse to take part in international exhibitions, but there is no real evidence that these exhibitions led to commercial success, as distinct from praise from the juries or the technical journals; in all other ways, the British makers publicised and sold their wares in much the same ways as their competitors.

Other influences on world prices of machine tools.

Three other factors could have affected the international trade in machine tools during the period from 1850 to 1914: transport costs, tariffs, and other government measures to encourage or protect home industries.

Assessment of the effects of differential transport costs on the export performance of the machine tool manufacturers seems impossible because of the complete lack of evidence on the subject. All that can really be said is based on negative evidence, that the question of direct transport costs is not mentioned by contemporaries as affecting decisions by customers on purchases of machine tools. There were apparently some differences in practice between different countries, British firms normally selling free on board, while some American firms sold c.i.f., but these differences do not seem to have been at all important. Indirect transport costs, principally the time involved in getting delivery from a foreign producer, were apparently of some importance, as had been suggested in the previous section, and many of the agency agreements which have been described were entered into to reduce the waiting times for imported tools, and to provide a quicker and more effective service for spare parts.

It is very difficult to see that any one country had any great advantage in transport costs over any other, particularly with the fall in Atlantic shipping rates during the period, and it therefore seems unlikely that transport costs can provide an explanation of the trends in international trade in machine tools which have been [illegible].

Tariffs, on the other hand, were definitely thought to have a serious effect on international competition in machine tools. Haranger, quotes, for instance, from the report by a French manufacturer, Émile Chouanard, on the Saint-Louis exhibition of 1904:

> "Dans ce document, ce constructeur montre l'écart considérable qui sépare les industries mécaniques françaises et américaines, fait ressortir l'impossibilité pour le matériel européen de pénétrer dans ce vaste marché bénéficiant de droits de douane 'véritables prohibitifs' et demande que le tarif douanier français soit triplé.
> "Ce tarif, en effet, élaboré en 1897, [illegible] à une protection de 3 à 6% (suivant la grosseur des machines) contre 45% aux États-Unis."[98]

An assessment of the effects of tariffs on the trade in machine tools is complicated by the multiplicity of different tariffs, by the differences in methods of assessment, and by the frequent changes which were made to tariffs during the period. Table 4, 2, shows the rates of duty levied at different dates between 1863 and 1908 on British machine tools exported to various countries, as calculated, at the dates given,

98 Haranger, [illegible] <u>Politique intérieure d'une grande industrie</u>, [illegible].

COUNTRY		1876-9	1876	1880	1882
Russia		2/11d	2/11½d	2/11½d	3/10d
Sweden		nil	nil	nil	nil
Norway		nil	nil	nil	nil
Germany (Z.V.)	Cast Iron	1/6¼d		1/6¼d	1/6¼d
	Wrought I.& S.	2/6½d	1/-¼d	2/6½d	2/6½d
	Other metal	4/10½d		4/10½d	4/10½d
Holland		1% ad.val.	1% ad.val	nil	nil
Belgium	Cast Iron	9½d	9½d	9½d	9½d
	Wrought I./S.	1/7½d	1/7½d	1/7½d	1/7½d
	Other	4/10½d	4/10½d	4/10½d	4/10½d
France 75%	Cast Iron	2/5¼d	2/5¼d	2/5¼d	2/5¼d
50-75%	Cast Iron	4/-¾d	4/-¾d	4/-¾d	4/-¾d
50%	Cast Iron	6/1d	6/1d	6/1d	6/1d
Portugal		5¼d	5¼d	5¼d	6d
Spain		6% ad.val.+ 1¼d per cwt.	6% ad.val	3/8d	3/8d
Italy		9¼d	1/7½d	2/5¼d	2/5¼d
Austria	Cast Iron	2/3½d	2/3½d	2/9	not iron 10/8d
	Wrought I. or S.	4/-¾d	4/-¾d	4/-¾d	75% cast 5/1d
	Other	8/2d	8/2d	8/2d	other 6/1
Switzerland		1/7½d	1/7½d	1/7½d	1/7½d

1883-5	1890	1893-4	1897	1901	1905	1908
11/10d	13/10d	15/1d	13/10d	13/9½d	13/	21.7.7d
nil	nil	10% ad. val.	10% ad. val.	10% ad. val.	10% ad. val.	10% ad. val.
nil	nil	nil	nil	nil	nil	10% ad. val.
1/6d 2/6d 4/10½d	1/6d 2/6d 4/-½d	1/6d 2/6d 4/-¾d	1/6½d 2/6d 4/-¾d	1/6½d 2/6d 4/-¾d	1/6d 2/6½d 4/-¾d	<250kg. 6/- 250-1000 4/- 1000-3000 3/- 3000-10000 2/6 >10000 2/-
nil	nil	nil	nil	nil	nil	nil
9¾d 1/7½d 4/10½d	9¾d 1/7½d 4/10½d	9¾d 1/7½d 4/10½d	9¾d 1/7½d 4/10½d	9¾d 1/7½d 4/10½d	9¾d 1/7½d 4/10½d	9¾d 1/7½d 4/10½d
2/5½d 4/-¾d 6/1d	2/5½d 4/-¾d 6/1d	<250kg 20/4d 250-1000 6/6d >1000 4/-¾d	20/4d 6/6d 4/-¾d	20/4d 6/6d 4/-¾d	20/4d 6/6d 4/-¾d	20/4d 6/6d 4/-¾d
6d	3/5d	< 50kg 13/9d 50-100 11/5d 100-500 9/2d 500-1000 6/10d >1000 4/7d	13/9d 11/5d 9/2d 6/10d 4/7d	13/9d 11/5d 9/2d 6/10d 4/7d	13/9d 11/5d 9/2d 6/10d 4/7d	13/9d 11/5d 9/2d 6/10d 4/7d
3/3d	3/3d	3/2d	7/6¼d	7/6¼d	7/5¼d	<500kgs. 10/2 >500kgs. 3/1½
2/5½d	3/3d	>300kgs 3/3d	3/8d	3/8d	3/3d	3/3d
10/2d 5/1d 6/1d	15/3d	<10000kg. 12/2d >10000kg. 5/1d	12/2d 5/1d	12/2d 5/1d	12/2d 5/1d	3/5½d
1/7½d	1/7	1/7½d	1/7½d	1/7½d	1/7½d	<1000kg. 6/6 1000-2000 4/10½ 2000-2500 3/3 2500-10000 2/10 10000-50000 2/5½ >50000 2/-

COUNTRY	1868–9	1876	1880	1892
U.S.A.	45% ad. val.	45% ad. val.	Iron [illegible] ad. val.	35%
			Steel 45% ad. val.	45%

TABLE 4. 2.

1884–5	1890	1893–4	1897	1901	1903	1908
45%	45%	45%	45%	45%	45%	45%

Table 4.2

by the Board of Trade. It is clear that the general trend of duties levied on British goods was upwards. The most spectacular increase in duties on machinery was that on imports to Russia, but particularly from the 1890s onwards duties were raised sharply in France, Portugal, Spain and Austria, and there were later increases in the duties on imports to Germany and to Switzerland. A further difficulty in assessment of the effects of tariffs is that the duties given in table 4, 2, applied to British exports, but not necessarily to those of her competitors, because of the operation of reciprocal tariff agreements and the most favoured nation clauses. In 1897 the editor of the 'American Machinist', reporting on a European tour, quoted rates of duty on the import of machine tools which showed variations in rates of duty applicable to British and American tools imported into Austria, France and Spain, although in all other countries goods from both those countries carried the same rate of duty. The full table is given below as table 4, 3.[99]

Apart from discrimination of this kind against American exports, it is likely that the method of assessment of duty produced differential duties as between Britain and her competitors. The round of new tariffs introduced in the early 1890s, of which the French Méline tariff is the best-known, introduced a system of duties according to the weight of the machinery. By 1903, as

99 Miller, 'Progress of American machine tools', May 27, 1897, Vol. 30, p.389, 'American machine tools abroad'.

Country of Import	From . . .	[illegible] Britain
France (under ½ ton)	60	40
(over ½ ton)	36	24
Spain	50	40
[illegible]	42.[illegible]	7.[illegible]
Germany	7.50	.50
[illegible]lgium	4	4
[illegible]itzerland	3	3
Russia	65	65
Denmark	12	12
Italy	24	24
Finland	31	31

TABLE 4, 3. Import duties on machinery per metric ton, in U.S.

can be seen from table 5, 2., this system, although with individual variations on the cut-off points between different rates, was in operation in Germany, Portugal, Spain Italy and Switzerland, as well as in France. In all these cases, the rate of duty lessened as the weight of the machine tool increased, thus discriminating against the lighter machine tools, of which the American tools were the most prominent example.

The tariffs were further complicated by differences in the methods of assessing weight, some countries using the gross weight including packing, other countries using net weight; inexplicably, while Germany in 1908 assessed machine tools on net weight if they weighed less than 1,000 kilograms, and on gross weight if they weighed more than 1,000 kilograms, Switzerland at the same time used gross weight if the machines weighed less than 10,000 kilograms, and net weight if they weighed more. The effects of such regulations can be seen in the slightly hopeless note appended to an order to Greenwood and Batley : "Duty in Switzerland being payable on the gross weight, packing is not to be unduly heavy; at the same time it must be sufficiently strong."[100]

The effective tariff rate payable thus depended on the country of origin, the weight of the machine tool, and, in the case of a number of countries at some periods, on the metal of which it was made. Calculation of the

100 Greenwood and Batley Ltd., Orders for Societe Industrielle Suisse Orders 772-787/17, December 1[illegible].

actual percentage tariff payable is thus extremely difficult. As an example, using the Greenwood and Batley material to arrive at average weights and prices for the machines which they sold, it appears that the highest percentage tariff was that of the United States, at 45%. The other tariffs payable, based on average weight per machine in 1894 of 52 cwts, and an average price of £145, were (to nearest 1%) :

Russia	27%	France	7%	Norway	nil
Austria	21%	Italy	7%	Holland	nil
Spain	14%	Switzerland	3%		
Sweden	10%	Germany	3%		
Portugal	8%	Belgium	1%		

Had the machinery been of the same price and weight, but made in the United States, based on the figures given by Miller the percentage duties would have been 10% in France, 18% in Spain, and 26% in Austria-Hungary.

It is clear from these figures that the tariffs imposed by America and the European countries could have made a substantial difference to the price of machine tools. The 45% American tariff in particular must have been effectively a prohibitive tariff, and the Russian tariff must have become so by 1908. On the other hand, it is clear that the history of tariff barriers to trade in machine tools can do little to explain the chronology of the development of trade in machine tools, or the paradox of the slow American penetration of the European market before 1895. As is clear from the figures given above, the huge American export success of the years

after 1895 came at a time when tariffs on American goods were higher than they had ever been before, and moreover were higher in 3 countries than those on the products of any of their competitors. All that can be said is that the gradual raising of tariffs which can be seen in this period must have operated to reduce, or slow down the growth in, international trade in machine tools, although the only country against whom discrimination was practised, the United States, does not appear to have suffered seriously

The development of trade in machine tools was also affected by the actions of governments in other fields than tariffs. At the same time as raising the duties on machine tools, the Russian government for instance tried by other means to encourage the growth of a native machinery industry. The directors of Greenwood and Batley, who sold a large number of machines to Russia, were told in February 1897 that an Imperial edict had been published ordering that as much work as possible should be done within Russia, and that the import of engineering machinery should be discouraged. Greenwood and Batley's response to this threat was to set up in Russia the Phoenix Engineering Works, wholly owned by an English subsidiary called the Anglo-Russian Engineering Company, so as to obtain the advantage of Russian protection of home industries. The <u>American Machinist</u> ascribed the reasons for this to the policy of the Russian government in favouring its own "industrial establishments" in placing orders for machinery for the construction of the Trans-Siberian railway, together with high tariff duties and high freight charges on

imported heavy machinery :

> "The situation has led to a clear perception of the fact that, particularly for heavy tools, a shop located in Russia will have a very great advantage; and a shop in which it is intended to build such tools is now being put up at St. Petersburg, the capital coming partly, or perhaps mainly, from England, and the equipment from the shops of Greenwood and Batley of Leeds."

It was believed that further factories might be established in Russia in this way, "primarily with a view to government orders".[101] It is not clear how successful this enterprise was, since in 1911 the directors were told that :

> "the outfit and plant were not arranged for producing small tools for which there was a market in Russia, and buyers there preferred to have German or American tools",

but the fact that it was thought worthwhile to attempt to get round Russian dislike of imports in this way demonstrates the threat which such government intervention could be to the machine tool trade.[102] Similar government intervention can be seen as working to the advantage of British machines, in that they received orders from the crown agents for the colonies, and received the benefits of imperial preference.

It thus seems unlikely that government intervention in the form of tariffs or the protection of home industries, or the influence of transport costs, can be an adequate explanation of the development of trade in machine tools.

101 American Machinist, Vol. 5, 1897, pp. 20, p.573.

102 Greenwood and Batley, Minutes of the Board of Directors, p. 12, 1897, May 23, 1897, Oct. 12, 1911.

or in particular of the American export invasion. It is of course possible that the effects of tariffs was to reinforce other tendencies; Carden reported in 1909 that :

> "The value of the protective tariff to American machine tool builders appears to be well appreciated among machine tool men in the United Kingdom, and it is my observation that among British machine tool makers there is a strong desire for like protection in Great Britain."

and he added that this was because a protective tariff would enable British tool makers to specialise.[103] This question will be considered further in the next section.

Other hypotheses.

It is clear from the preceding discussion that the major problem in considering international trade in machine tools is to explain why the entry of the United States into the European market for machine tools was so long delayed, why it came in the middle of the 1890s, and why it was so immediately successful.. There are a number of possible solutions to this problem, of which two, a possible failure in British sales effort, and the effect of tariffs and other artificial barriers, have been discussed and provisionally rejected as possible explanations. The rejection of these possibilities leaves two possible lines of explanation, that the supply of machine tools from America and her competitors changed in such a way that American tools became more attractive and competitive in European markets, or that the demands of European buyers of machine tools changed in such a way that American tools

103 Carden, J.L. 'Machine Tool Trade in the U.K.' (Washington: 1909), p.234.

now best suited their requirements. It is necessary, in fact, to discover whether the demand or the supply curve for machine tools changed in such a way as to produce the chronology which I have described.

Simplifying the problem very considerably, an explanation based primarily on changes in the demand curve would assume that the technical experts were right in their assessment of the superiority of American machine tools, but that demand conditions in Europe were unfavourable to their adoption until the 1890s. An explanation based primarily on changes in the supply curve would assume that the technical experts were wrong, but that in the 1890s the supply of American tools changed in such a way that they became attractive to European consumers.

One method of approaching this question would therefore be to attempt to examine directly the question of whether American machine tools were in fact superior to European tools, since a decision on this point would settle the question. Unfortunately, a direct answer on this question is impossible to achieve, principally because of the difficulty of defining what is meant by 'superior'. There seems to be little doubt but that American machine tool makers were more inventive than European makers, and that their tools were more ingenious in a technical sense, but from this point little progress can be made. It was argued, for instance, that American machine tools were too light to machine British iron, that they were not suitable for general production work but only for mass-production work which was uncommon in Britain, and that they were too complicated for British workmen to understand

In answer to this, it was alleged that British engineers did not use the tools properly, that they should have adopted mass-production, that the British worker should be better educated or freed from the malignant influences of trade unionism.

In the absence of an answer to the question of whether American machine tools were in fact superior, I am firstly going to assume that they were, and that the explanation of the chronology of trade lies on the demand side, and secondly that they were not, so that the explanation lies on the supply side.

British-American competition in the light of the assumption of American superiority in machine tools.

If one assumes that American machine tools were, from approximately 1870, in some way superior to European, and in particular British, machine tools, then it is surprising that American machine tools did not find a wider sale in Europe until 1895. If this explanation is the correct one, then it should be possible to find changes in demand in Europe at that time which explain the American export invasion.

There appear to have been three contemporary explanation of the American export invasion which would accord with this view :

1. That it was a consequence of heavy demand in Europe combined with slack capacity in the machine tool works through the domestic recession.

2. That it was a consequence of the demands of the bicycle industry.
3. That it was a consequence of the British engineering strike of 1897.

Of these the second and third explanations fall squarely within demand changes. The first is a hybrid of demand and supply changes, but is listed here because it was argued that it was the heavy demand from Europe which diverted American manufacturers from their concentration on the home market, although they were helped and encouraged by shortage of demand at home.

In an unsigned article, published in 1899, the American Machinist stated that "The beginnings of the European trade in American machine tools on a large scale was the outgrowth of the domestic trade paralysis of 1895-6" combined with the heavy demand facing British machine tool producers, which had produced long delays in deliveries.[104] This theory implies that before 1895 American machine tool makers, with a large home market protected behind a 45% tariff, had simply not bothered to expand capacity to sell in export markets. Faced however with a recession in domestic demand, they sought export orders to fill their underutilised capacity, and were successful in doing so because of an upswing in demand in Europe which could not be satisfied by European manufacturers. This theory was to some extent supported by J.L. Carden, who in 1909 wrote that in the past decade and a half although American exports had been rising this owed little to the enterprise of the makers, who had not been anxious to sell abroad since home demand was overtaxing their resources.[105]

104 Unsigned article, American Machinist Vol.22, July 13, 1899, p.627.

105 Carden, G.L. Vol. I, 1909, p.9.

This theory in fact implies that sales to Europe in the period from 1895 simply filled slack capacity, and were not an addition to normal production of American machine tool firms. It is possible to examine this through the records of Brown and Sharpe and Ballards which have been tabulated by Professor MacDougall. The relevant statistics, extracted from Professor MacDougall's article, are given below, as table 4, 4.[106]

These statistics do not appear to give any conclusive support to the 'slack capacity' theory. Although Brown and Sharpe's home shipments in 1891, at 282 machines, were lower than in any year since 1888, the trend in home sales is clearly upward from about 1887, and the recession in the 1890s seems to make very little difference to the trend. There is also no sign that foreign shipments are taking the place of falling home sales; foreign shipments in fact fell in 1892 and 1893 to a level lower than had been achieved in each of the four preceding years, and although the trend is markedly upwards from 1895 onwards, so is the trend for home shipments for that period. In other words, the recession in 1892-4 appears to affect both home and foreign sales, and the recovery in the following years also produces an expansion in both types of sales; there is no sign, in these figures for shipments, of foreign sales being sought to replace a failing home market. It is of course difficult to make this judgment very definite; it is possible that the fall in sales in 1892 led Brown and Sharpe to fear a prolonged recession in home demands and therefore to begin to seek foreign orders. Given the lag between order

106 MacDougall, [illegible], Tables 3-2, -3, pp. 515-6.

Year	Number of Machines – Brown and Sharpe			
	b. Total	c. Home	d. Foreign	$\frac{d}{a}$ .100
1890	574	445	129	[illegible]
1891	500	396	104	[illegible]
1892	541	450	91	[illegible]
1893	522	434	88	[illegible].9
1894	392	282	110	.1
1895	815	638	177	[illegible].7
1896	1015	560	455	[illegible]
1897	1206	444	762	[illegible].2
1898	1508	719	789	[illegible].3
1899	1962	1205	757	[illegible].6
1900	1666	928	738	[illegible].3

Year	Number of Machines – Bullard			
	e. Total	f. Home	g. Foreign	$\frac{g}{f}$ .100
1890	192	188	4	[illegible].1
1891	155	149	6	[illegible].3
1892	169	168	1	.6
1893	113	113	0	0
1894	56	56	0	0
1895	96	92	4	.2
1896	135	100	35	[illegible].9
1897	155	64	91	[illegible].7
1898	273	129	144	[illegible].7
1899	334	151	183	[illegible].8
1900	319	143	176	.2

TABLE 4, 4. Shipments of tools by Brown and Sharpe and the Bullard machine company.

and shipment it is possible that the results to this export effort did not come to fruition in shipments until 1895-6, by which time home sales were again showing an upward trend. In other words, Brown and Sharpe began to expert to cope with an expected fall in demand which did not actually materialise. Since no information is available on the timing of orders as opposed to shipments it is impossible to decide this point, but it is at least clear that the shipment figures which are available do not support any hypothesis based on an export drive to use capacity unemployed on home orders.

The Bullard evidence is difficult to interpret because of the small numbers of machines sold, at least in comparison with Brown and Sharpe's shipments. There is however, a clear break in the trend of the company's home sales between 1893 and 1897, and it is at the end of this period that the first substantial foreign sales in the history of the company are recorded. It is again possible that these sales reflect an export drive in 1893 to 1895, in an attempt to utilise capacity under-used because of the home recession, but again it would be necessary to have information on the timing of orders before any certainly could be achieved.

The evidence from Brown and Sharpe and Bullard is thus not entirely conclusive on the influence of the home recession on the expansion of exports. The evidence of both companies does however concur on one point, that after 1897 there is no slackening in export sales as a result of expanding home demand. If the response to

slackening home demand was to seek new markets, then the response to a renewal of home demand was not to desert these new markets, but rather presumably to expand capacity to cope with both home and export markets. It may be asked why this had not been done before; it seems possible that the home recession was a catalyst, but it is arguable that the immense expansion of American sales owed more to demand conditions in Europe than to supply conditions in the United States, since it is difficult to see why expansion of capacity should have become so much easier in 1897 if it had been so difficult five years previously.

The explanation of the American export invasion in terms of a home recession does not, for these reasons, seem entirely satisfactory. The second explanation is that the demand for American machine tools arose as a result of the bicycle boom in Europe. It is certainly clear, from the remarks of Charles Churchill, the leading British importer of American tools, which have already been quoted, that the bicycle boom was a powerful stimulus to the use of American tools. An English engineer told the Manchester Association of Engineers in 1898 that "The bulk of the tools in the cycle works at Coventry came from America".[107] A theory which ascribes the American export invasion to the bicycle boom must however explain why this particular industry provided such a demand, why that demand could not be satisfied within Europe, and thirdly why the demand for machine tools from America continued long after all the bicycle works must have been fully equipped.

One possible explanation is that the bicycle trade

107 Webb, Henry, "English and American Methods in the Engineering and Iron Trades" printed in Engineer, Vol. 85, Jan. 21, 1898, p.66.

demanded machinery capable of mass-production of interchangeable parts, and that only the American machine tool makers were used to the production of such machinery. On the other hand, the sewing machine and small arms trade had similar requirements, and had been supplied with many machine tools by British makers, and the bolt, screw and nut making industries were similarly supplied with English machinery. English machine tool-makers were in fact often criticised because of their production of the special-purpose machinery used by the mass-production industries, since this precluded them from making large quantities of machine tools on a production line basis. Any explanation based on the technical incapacity of British tool makers as compared with their American rivals is therefore difficult to sustain.

A more plausible explanation for the way in which the bicycle producers turned to the United States for their tools is simply that the Americans had already experienced a bicycle boom and were therefore skilled in their manufacture, and that British and other European toolmakers were occupied with other work and unwilling to launch into a field in which they were at an obvious disadvantage. This could explain why Greenwood and Batley, who were the largest producers in Britain of the highly specialised mass-production small-arms machinery, did not enter the market for bicycle machinery, with the exception of a few odd sales. They were also occupied at this period with other orders. It is perhaps important in this context that the most successful British producer of machinery for the manufacture of bicycles, Alfred Herbert, was a new firm without established customers in other fields of machine

tools, and was moreover situated in the Coventry and Birmingham district where many of the early bicycle factories were set up; it was therefore heavily dependent on the bicycle trade, and could concentrate on the design and construction of the highly specialised machinery which was needed. It is interesting that as has already been noted Alfred Herbert rejected suggestions that he should specialise in one type of machinery, as the American firms did, on the grounds that :

> "The cycle business, which was our principal customer, required in those days a variety of machines, and not many of them of one kind. Besides the hand lathes... we made specialised machines for turning, boring, drilling, tapping and lapping hubs, for bedding rims, for drilling rims, for sharpening cutters, and were able to keep ourselves well employed." 103

This is confirmation of the fact that the manufacture of bicycles required exactly the special purpose, specially designed machine tools at which the British were said to excel, and which the American system of mass production of machine tools did not produce.

The explanation for the export invasion in terms of the bicycle boom is thus not entirely satisfactory, although demand for bicycles must, as the evidence of Churchill's shows, have played a major role in promoting demand for American tools. It is still not clear, however, why the demand generated by bicycle factories should have continued after the demand from those factories must have largely ceased.

103 Herbert, Sir Alfred 'Machine Chasers - Alfred Herbert Ltd' A section of Herberts manuscript autobiography.

One possible explanation, which links with the third explanation of the American invasion, is that the American machinery could be introduced into the bicycle trade because that trade was a new industry, not subject to trade-union restrictions. The engineering strike, in which the workers were defeated on the introduction of automatic, labour-saving machinery, then allowed the introduction of new machinery throughout the engineering industry; much of this was bought from America, since the American machinery had been so successful in bicycle manufacture. Miller, the editor of the American Machinist, commented in 1897, just before the beginning of the strike, that the British unions were generally said to be hostile to the introduction of new machinery, putting impossible restrictions on its use :

> "It is explained that our labor-saving machinery has been largely put into the bicycle factories here, and has worked well, because that is a new industry and mostly new men have been put to work in it - men that have few or no preconceived ideas of what amount of work a machine ought to do or how it ought to do it, but simply operated the machines as they were instructed."[10]

After the strike, an editorial in the 'Engineer' commented that the failure of the strike had removed limitations on the use of automatic tools :

> "Manufacturing engineers of all sorts are, since the conclusion of the strike, and in consequence of their improved position with regard to their employes which that strike brought about, removing or not purchasing machines of the old type, but are adopting the new patterns".

Since English makers were very busy, and were making tools for smaller shops and jobs where automatic tools were not suitable, orders for these new machines were going to America.[110]

109 Miller, Fred "American Machinist", Vol,20, p.413,June17,18

110 Editorial 'English and American Machine Tools' The Engineer, Vol, 86, Dec. 2, 1898, p.543.

It is extremely difficult to judge the truth of these statements, since so many of the writers on this subject revealed so great a bias against any form of trade unionism that their views are hardly objective. It is certainly true that the 'machine question' as it was known to the Unions, was one of the issues in the 1897 strike.[111] In the terms of settlement of the dispute, which represented a victory for the employers, it was agreed that employers should have the right "to appoint the men they consider suitable to work...(the machines)... and determine the conditions under which such machine tools shall be worked." and the 'right to select and train' their workers was used by the employers between 1897 and 1914 to man machines with unskilled labour.[112] It seems therefore that the engineering strike may have opened the way to the introduction of semi-automatic machinery, and that American machine tool-makers took advantage of this, the British manufacturers, at least in general, being unable or unwilling to do so.

It seems therefore that of the three explanations which were advanced by contemporaries of the American export invasion in the mid-1890s, a combination of the effects of the bicycle boom and of the strike of 1897 may explain at least partially the introduction of American machine tools into England after 1896. In the case of other countries, the bicycle boom was a feature of both French and German engineering at this period, and it seems likely that some American machine tools were imported into those countries to meet its demands. It seems unlikely however that the British engineering strike could have had such effects, although it didcertainly lead to lost orders

111 Jeffreys, J. B. 'The Story of the Engineers'(London:1945 p.142-3.

112 Jeffreys, op.cit., p.145, 156.

and to a failure to complete machines in time which may have opened up opportunities for American exporters, and may for instance be responsible for the permanent fall in Britain's share of machine tool imports into France.

This section has been concerned with explanations of the timing of the American 'invasion' based on the hypothesis that American machine tools were in some sense superior to those of the European producers. Taken together, these explanations suggests that it was inertia or conservatism on the part of British and European customers, together with American pre-occupation with the home market, which had prevented an American 'invasion' of European markets before the middle of the eighteen-nineties. In this period it is argued, demand conditions in Europe, and supply conditions in the United States, changed radically, and allowed American machine tools to enter European markets. Once there, the technical qualities of the tools were appreciated, and American producers gained a permanent place in the European markets, largely at the expense of the British.

It has been shown that the timing of the American export invasion of Europe in machine tools does lend some support to this view, which was certainly held strongly by many contemporary commentators. There was, in the middle eighteen-nineties, a slump in domestic demand in the United States and a boom in Europe, and in the particular field of machine tools the demands of the bicycle industry added extra impetus to the generally favourable demand conditions. The British exporting and home sales efforts were also weakened by the engineering strike.

At the same time, there remain several puzzling features about this general explanation of the timing and causes of the American challenge. Firstly, this explanation does not resolve the difficulty that American machine tools were praised by European commentators for nearly thirty years before this period, and yet did not secure any substantial sales in Europe; if the machine tools were in fact so superior, this delay seems curious. Secondly, this explanation does not explain satisfactorily the permanence of the American invasion, which might have been expected to have declined when the particular demand and supply conditions in the European markets altered, as they rapidly did. Thirdly, the ascription of the American success to the demands of the bicycle industry ignores the very similar demands, earlier in the century, from other mass-production industries, notably small-arms and sewing-machines; if these industries, which certainly brought some American tools, did not spark off the American invasion, why then did the bicycle industry do so?

In the light of these difficulties, it is necessary to re-examine the assumption which was axiomatic to many contemporary commentators, that American machine tools were in fact, for the purposes of European metal manufacturers, superior to the machine tools produced by British or other European firms.

<u>British-American competition without an assumption of American superiority in machine tools</u>.

Since an explanation based primarily on demand does not seem entirely satisfactory, I now want to examine

British-American competition to see whether changes on the supply side were significant. Since this involves relaxing the assumption that the technical experts were right, and arguing in fact that american machine tools were not so superior to those of her competitors, this is an appropriate place to examine the evidence on this point.

There is unfortunately no unanimity among contemporary commentators on this issue, but their comments can, at least for the sake of clarity, be divided into two broad groups.

The first group disputed the technical superiority of American tools, concentrating particularly on their supposed flimsiness. The second group admitted the ingenuity of the designs of American machine tools, but argued that they were not suited to European conditions; the conditions which they thought of were particularly the skills of the workers, the type of work, and the markets for tools and other engineering products.

The alleged lightness, lack of durability, and shoddiness of manufacture of American machine tools was a favourite theme of commentators on machine tools, the American tools being contrasted with the well-built, solid and long-lasting British tools. There is no doubt that, to most British engineers, solidity was in itself a virtue. R.S. Burn, commenting on the London exhibition

of 1862, praised the 'massive' machine tools which were displayed, and saw them as the results of 'the requirements of the more recent period (which) appear to have progressed amazingly in the direction of speed, bulk and power'.[113] while an American praised British tools at the Paris exhibition of 1867 as 'models of solidity and excellence of workmanship'.[114] In 1890 S. Dixon, an English engineer, reporting on a trip to the United States, commented that American machinery was much lighter than British, perhaps by 25-30%, and explained that :

> "We in England had been tending in the direction of solidity and strength in all our machinery, and in America they were gradually changing in the same direction, but they were still some years behind."[115]

In the same year the Institution of Mechanical Engineers were told, in a paper by George Addy entitled 'On Milling cutters', that "The milling machines originally imported from America and the Continent were deficient in the solidity and stiffness which constitutes the first requirements for the production of good work."[116] G.L. Carden admitted in 1909 that there was a difference between American and British tools in solidity; he reported that British tools were preferred at the Dubosc machine tool works in Turin, "because of their rather heavy proportions. Some American turret lathes do appear a trifle light in close comparison."[117]

113 Burn, R.S. "Modern Mechanical Engineering and Machine Making" (Edinburgh: 1869), p.198.

114 "Engineering facts and figures" (1868)

115 "English Criticisms on American Engineering Work", Engine Vol.70, Dec. 12, 1890, p.476. This article was a report of a meeting of the Manchester Association of Engineers which had been addressed by members of a recent trip to the United States organised by the Iron and Steel Institute.

116 Addy, George 'On Milling Cutters'. [illegible] (1890), p.535.

117 Carden G.L. Vol. I, Italy, p.200.

The preference of British machine tool makers and engineers for heavier machinery than was acceptable in the United States was not based entirely on sentiment, although tradition played a part, as the '[illegible]' suggested in an article in 1907 : "Machine tools have hitherto been built very much on empirical formulae, and on the basis that the part cannot be too strong..."[113] The justification for the British liking for heavier machine tools shades into the second grounds for disputing the superiority of American machine tools, the argument that American machine tools were not suitable for European conditions. It was argued simply that British iron was harder than American [illegible], so that British machine tools had to be built with greater strength or they would fall to pieces in trying to take cuts from the metal. In 1899 the 'Engineer' commented that English tools were more durable than the American tools because they were made of harder cast iron, although there was the compensating [illegible] that English iron was liable to fracture more easily.[119] In the American Machinist in 1902 [illegible], in an article called "An English view of American tools" went into the question fully. He stated that changes in the English machine tool industry had been slow because the machinery had been so durable, English tools being made of harder iron, and continued :

> "Old English machine tools were certainly obsolete before they were worn out- they never did seem to wear out because they were made of such hard iron, and held even the chaping marks for .... I have gone carefully into this question o[illegible]

113 'Engineering in 1906' Engineer 103, [illegible]. 4, 1907, p.1. Those remarks were [illegible] a justification of the magazine in printing articles on machine tool design, since "designers are, perhaps, a little disposed to look on such a scientific enquiry as this as an act of supererogation"

119 'English and American machine tools, III, their Comparative Durability and Cost.' Engineer, [illegible], Dec., [illegible], p.[illegible].

> "of cast iron and, personally, I have no shadow of doubt that English cast iron is very much harder than anything that comes from outside. The wear that takes place in American tools manifests itself in two ways; first, it compares with the wear on our own hard irons; and, secondly, American tools made to cut American iron were too light and had surfaces too small when set to cut our hard iron. Then, the attempt to run the tools at the speeds stated they would run was provocative of disaster. Failure was laid to British clumsiness on one side and to Yankee flimsiness on the other. Sober-minded men realised that the whole matter was one of materials." 120

F. Foster, writing on 'Engineering in the U.S.' explained that the Americans were, in 1906, making their machines more durable, but still :

> "In connection with American machine tools and machinery generally, one finds a more extensive use of a soft grade of iron which is easy to work, but materially shortens the life of the machines where accuracy of adjustment is essential."121

L.T.C. Rolt points out that, as Roe described, William Sellers :

> "... realised that American machine tools were being built then too light, and they both, (Sellers and another designer, Bement) put more metal into their machines than was the practice elsewhere."122

but this passage emphasises that normal American practice was to build light machines.

The equation of solidity and weight with strength was naturally disputed by American machine tool makers, but it was further argued that it was undesirable for machine tools to be too solid and durable, since in a field where technical

120 Booth, William H. 'An English View of American Tools', American Machinist, 25, Nov. 6, 1902, p.1573.

121 Foster, Frank Engineering in the United States, (Manchester, 1906)

122 Rolt, L.T.C. Tools for the Job (London, 1965), p.175.

progress was so swift it was undesirable for an engineering manufacturer to possess a large number of workable but technically obsolete machine tools. In other words, it was argued that machine tools should be designed to standards which would give them a workable life only until they were superseded by a new tool, at which point they could be scrapped without compunction or fear of waste. Thus in the series of articles published by the 'Engineer' in 1899 comparing American and British machine tools, in the article on comparative durability and cost it was stated that :

> "Formerly, when skilled labour was comparatively cheap, and manufacturers of machinery few, this point (of durability) was without doubt a matter of great importance; and one could sympathise with the owner of a tool who, having done it up thoroughly after, say, 25 years hard work, could point out with pride that it was as good as new. Now-a-days, when labour is costly, the firms who manufacture machine tools are hammerable, and scarcely a day passes without improvements being introduced, the durability of machine tool beyond a certain limit not only ceases to be an advantage but is positively undesirable."

The article continues by advising that worn out tools should be scrapped rather than repaired, and concludes that many manufacturers :

> "would be in a better position at the present moment had their original machinery been less durable, and had they been forced, in consequence, to keep their plant up-to-date from time to time by the purchase of new machinery." 123

It is clear that there was no unanimity on the desirable technical characteristics of machine tools, particularly as the discussion was in such general terms.

123 'English and American Machine Tools,...' Engineer loc.cit., p.559-60.

lumping together heavy and light machinery, and machinery designed for so many different purposes. On the other hand, it is interesting that British machine tool makers could argue that the differences in strength and weight between British and American tools, so often regarded as a proof of British technical backwardness, were simply dictated by the quality of the metal to be machined. Whether this was in fact a correct argument could only be determined by an analysis of the metals produced in Britain and America, but it is obviously a point which needs to be borne in mind, particularly in the light of the numerous discussions of British and American technology which entirely ignore differences in the quality or other characteristics of the raw materials.

It is thus possible that there were significant differences between British and American machine tools explicable not so much in terms of the technical superiority of one or other country but rather in terms of the jobs which each country's tools had to perform. That there was such a difference was secondly argued with relation to the markets for which makers of machine tools in each country were manufacturing. British tool makers argued that the demand with which they were faced made it necessary for them to produce a large number of different types of machine tools, adapted to the special needs of each customer, while American makers, because of their large, protected, home market, could afford to concentrate on the production of only a few, or even one, type of machine tool, with all the economies of production and distribution which this entailed. The character of

the market was thus regarded as a primary factor in the difference between tools, and between manufacturing methods, of British and American makers, the other European makers generally following British rather and American models. Professor Saul has also recently emphasised the role of the customers in retarding British technical progress in engineering goods during this period.[124]

It is clear that, by the end of the century, it was generally thought that there was a clear distinction between American machine tool makers and their European rivals in the number of different types of machine tools which were made by a normal firm. Evidence for this widely-held belief is surprisingly difficult to obtain. Brown and Sharpe made at least six types of machine tools, as well as different variations on these types; in addition they remained successful manufacturers of sewing machines throughout the period.[125] Alfred Herbert, the British firm regarded as most closely following American practice, felt it necessary to make many types of tools, as the statement from the founder quoted above demonstrates.[126] It is possible that the specialisation was in fact less marked than many people thought, and was restricted, at least until this century, to a decision to make heavy rather than light tools, or to specialise in machine tools rather than making all types of engineering goods; this tendency has been discussed in the chapter above on the

124 Saul, S. B. 'The Market and the Development of the Mechanical Engineering Industries in Britain, 1860-1914' Econ. Hist. Rev., Vol. XX, 1, April 1967.

125 MacDougall, D., loc.cit. and records of the Company.

126 Herbert, Sir, Alfred, loc.cit. and see above.

structure of the industry. In addition, there may have been a tendency for a firm to concentrate its advertising, and perhaps its innovative effort, on a few tools, but to continue to make a wide range of tools in response to orders.

The whole subject of the introduction of mass-production and specialisation into the machine tool industry is however one of considerable complication. It needs to be realised that, generally, tools which were to be used for specialised mass-production could not normally themselves be mass-produced, but had to be specially designed and made with a particular function in mind. The machine tool makers who did themselves mass-produce were therefore not normally producing specialised, mass-production tools, but rather making multi-purpose tools for the general engineering market. It is clear that the effects of the two types of specialisation, that by the customer and that by the machine tool maker, could be very different, and that to confuse them, as seems to have been done by many contemporary commentators, could be extremely misleading. It is this confusion which leads to the British machine tool industry in this period being accused of hostility to the growth of specialisation, when in fact the most potent criticism that can be made of it is that is clung for too long to the traditions of the manufacture of machine tools minutely designed to fit the wishes of each individual customer. It is important also to realise that the advent of specialised machine tool makers produced a change in the relationship between the machine tool maker and his customer which was not always to the advantage of the customer. The customer could no longer ask a machine tool maker to produce for

him a complete plant for the production of an article, but had to search around among many manufacturers for the tools which he needed to fit into the production line. An important part of the design process was thus transferred from the producer to the consumer; it is clear that this transfer must have been costly, and it is also clear that it was resisted for this reason, particularly by foreign customers who could not shop around for tools among a number of different manufacturers, especially in view of the indifferent quality, in terms of the amount of technical data given, of many catalogues. As A. A. Orcutt wrote in 1900, discussing the reason for the lack of specialisation among European machine tool makers,

> "Undoubtedly the peculiar state of the European machine tool maker has been partly brought about by their large export trade, and the fact that they undertake to produce every article called for by foreign enquiries and indents, where complete plants are required."127

When asked why they agreed to take orders on this basis, European machine tool makers referred partly to tradition, but largely to the fact that, with their small home markets, in the case of Britain unprotected from foreign competition, they could not afford to refuse any order which came their way. They therefore had to be prepared to produce, as Craven's were in the 1890s, "almost every type and size of machine tool then known, together with large numbers of special machines,..."128

127 Orcutt, A. A. 'Machine Tool Development in Europe and America', Engineering Magazine, Vol. XVI, 1898-9, p.355.

128 Green, A. 'Machine Tool Building in Britain, 26: Craven Brothers, (Manchester) Ltd.', Machinery, No. 5, 1965, p.[illegible].

British and other European engineers were therefore used to the purchase of purpose-built machine tools or sets of machine tools, and to what was described at the time as a 'client' relationship with a machine tool maker; they told him what they wanted done and he supplied the tools to do it.[129] Alternatively, they would employ a professional engineer to prepare specifications and supervise the work.[130] In America, on the other hand, the customer would work out the requirements of the job himself, and then consider different machine tools, made by different makers, until he found those which most nearly suited his [illegible].

It is, in view of the diametrically opposed systems practised in America and in the European countries, very difficult to decide which system was in fact superior, and almost impossible to decide whether the American system was in fact so superior as to be responsible for the success of the American invasion of European markets. The decision is further complicated by the fact that it is often unclear, when considering contemporary comment on this subject, whether the writer is referring to specialisation on the part of the machine tool maker or of his customers, or whether to specialised machinery or to mass-production machinery. It is apparently true that many customers thought that the American tools were too highly specialised, and therefore preferred presumably more generally applicable British tools,[131] although

129 Miller, Fred 'American and other Machinery Abroad' American Machinist, American edition, May 13, 1897.

130 Editorial, American Machinist, American edition, June 3, 1897.

131 Report of the British Commissioners to the Exhibition [illegible] 1910-1911 (P.P. 1912-13, XXII, 1) p.[illegible].

American engineers saw this as a sign of backwardness, and argued that the machine tool maker should educate his customers and persuade them to use the newer tools.[1,2] It seems likely also that the confusion over who was specialising led many customers to believe that American machinery was highly specialised and useful only for mass-production jobs, when in fact such machines as milling machines and turret lathes, the machine tools thought of as typically American, had much wider uses in general machine shops.

In the light of the admittedly flimsy and impressionistic evidence which has been presented on the different tasks which were thought to be required of American and European machine tools, it seems plausible to assert that one reason for the delay in the introduction of American machine tools into European markets was that they were not initially well suited to the needs of European buyers, or at least that European buyers did not think of American tools as suitable. If in fact American tools would not cut European iron then they were not, for European conditions, technically superior.

If American machine tools were not initially superior to European tools in their attraction to European customers then an explanation of the American export invasion in the 1890s should include some consideration of whether the machine tools supplied by American makers were being altered in any period in such a way as to be more attractive

1,2 Reports of the Royal Commission to the Paris Exhibition of 1900. (P.P. 1901, XXXI, 1) p.363.

to European buyers. Unfortunately, with the exception of the few remarks of contemporaries that American machine tools were becoming stronger, no evidence on this point is easily available. It would seem likely, in fact, that only investigation of the records of the American machine tool industry for this period could establish whether its products were changing significantly, and such an investigation has not yet been carried out.

A further possibility, which could again only be confirmed or denied through an investigation of the American machine tool industry, is that it was only in the 1890s that the American machine tool industry had expanded sufficiently to be able to cope with any demand apart from that from the American engineering industries. This explanation would suggest that, until the 1890s, there had been surplus demand for machine tools within the American economy; if this was so, it is difficult to see why other engineering firms did not begin to manufacture machine tools, in the same way as the British firms described in chapter 2 above entered the industry in times of high demand. On the basis of British experience, therefore, this explanation of the delay in American exports to Europe does not appear to be likely, but only deeper investigation of the American industry could provide a definite answer.

A last possible explanation of changes in the supply curve for machine tools, is that of relative price changes. If the mass-production and specialisation for which the American industry was famous was acting to reduce

prices, or alternatively if the backward European industries were increasing their prices, then such change in relative prices might provide a possible explanation for the American invasion. It is difficult to judge whether such changes occurred, because no comparable price series exist for American and European tools; no industry-wide series exist at all, and series for individual firms cannot easily be compared as there is no means of knowing whether output consisted of comparable machines. It is possible to construct series of mean prices for a number of types of machine tools exported to Great Britain by Brown and Sharpe, and these are given in table 4,5 , together with a series of mean prices for all sales by Greenwood and Batley, the only British producer for whom such figures are available.

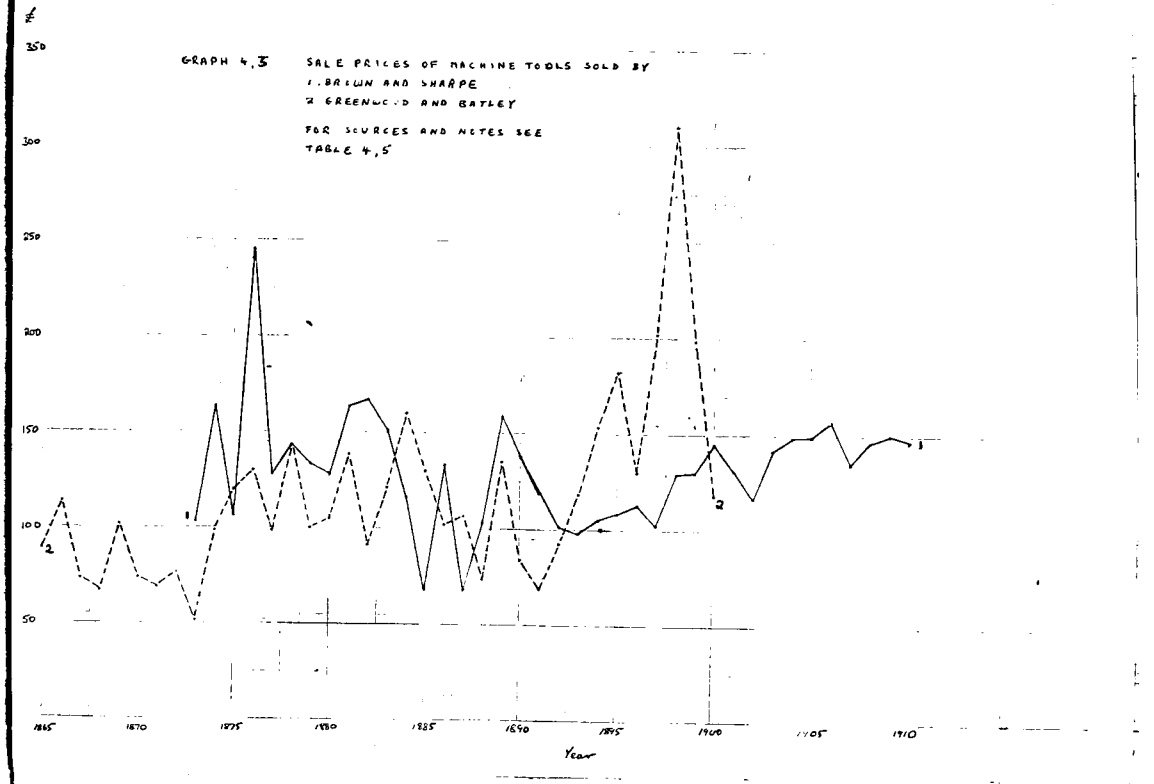
The variations in the two series for mean prices of all tools, columns e and f, make it very difficult to carry out any worthwhile comparisons, or to come to any meaningful conclusions about movements in relative prices, especially as it is not clear whether the American prices include freight costs. It appears that the general trend of Brown and Sharpe prices was downwards, and that of Greenwood and Batley prices upwards (in current prices), and graph4, 3, shows the two series plotted together to illuminate this. Furthermore, the individual series a to d seem to show reductions in the mean prices of Brown and Sharpe tools in the early part of the 1890s. It is however clear that these price reductions (if they were in fact that rather than changes in the mix of machines being sold) were very short lived, and it seems unlikely

Year	BROWN AND SHARPE Milling machines	Grinding machines	Gear-cutting machines	All machines	G All machi
1865	450			92	89
1866					113
1867		130		27	73
1868					67
1869					102
1870				174	74
1871	855			174	69
1872					77
1873	855			103	51
1874				163	98
1875	800			106	120
1876				245	130
1877	966	115		[illegible]	98
1878	700			143	143
1879	650		650	133	100
1880	675		650	128	105
1881	800			163	138
1882	1038	800		167	91
1883	1200	650		151	121
1884		673		116	160
1885		260		68	130
1886		950		133	102
1887				68	107
1888	683	442	750	103	74
1889	700	833	750	158	135
1890	705	534		137	84
1891	629	594		119	69
1892	[illegible]	385		101	93
1893	558	394	635	97	118
1894	649	363	550	105	153
1895	606	435	638	108	182
1896	598	369	1164	113	130
1897	520	434	815	103	202
1898	653	492	1013	129	310
1899	627	562	917	130	198
1900	638	651	1240	145	118
1901	638	557	1158	131	
1902	666	503	920	117	
1903	[illegible]	500	1020	142	
1904	[illegible]	559	1039	148	
1905	[illegible]	594	1081	149	
1906	835	688	1079	157	
1907	670	538	1138	135	
1908	911	536	1083	146	
1909	803	644	1183	150	
1910	727	617	1386	146	

TABLE 4.5 **Mean prices of machine tools sold by:**
a. Brown and Sharpe Ltd. to Great Britain.
b. Greenwood and Batley Ltd. to Great Britain and other countries.

Notes:-
1. Mean prices for individual tools sold by Brown and Sharpe are for sales to England.
2. Mean prices for all tools sold by Brown and Sharpe are for sales to England and Scotland.
3. Mean prices are in current dollars for individual tools. Mean prices for all tools sold by Brown and Sharpe are in constant £ sterling, converted from dollars at the rate of 4.90 dollars=£1. Prices for tools sold by Greenwood and Batley are in £ current.

Sources:-
1. Sales records of Brown and Sharpe Ltd.
2. Sales records of Greenwood and Batley Ltd.



GRAPH 4,3 SALE PRICES OF MACHINE TOOLS SOLD BY
1. BROWN AND SHARPE
2 GREENWOOD AND BATLEY

FOR SOURCES AND NOTES SEE
TABLE 4,5

that they could have had so considerable an effect as to provide a complete explanation for the American export invasion. It should further be remembered that the 1890s were a period of considerable difficulty for Greenwood and Batley, that their costs were forced up by heavy expenditure on rebuilding and re-equipment, and that their prices may not be representative of prices in British industry as a whole.

Conclusion.

The evidence which has been discussed in this chapter suggests most strongly that no simplistic, or mono-causal, explanation of the trends of international competition in machine tools is adequate. Each of the possible explanations which has been presented for the growth of American competition has its merits and demerits, but none is viable by itself, and it has not been possible in this discussion to analyse the competition from Germany and other European nations; it is likely that any such analysis would produce other possible explanations for the trends which have been observed.

Unless some explanation has been overlooked or misconstrued, it is likely that the explanation for the most dramatic change of the later nineteenth century, the entry of the United States into world markets for machine tools, lies in a mixture of the various factors which have been described. The overall explanation which would cover everything is that, in the 1890s, the technical and commercial requirements of American and European engineering first converged to an extent sufficient for the both

to be considered as sharing the same technology. The large demand from Europe for bicycle manufacturing machinery, which European machine tool makers either could not or would not satisfy, coincided with slack capacity in the United States, and occurred at the same time as the American machine tools were being built sufficiently solidly to meet European requirements. The relative price of American tools may also have been decreasing. Once European makers experienced American machine tools in bicycle manufacture, they were convinced of their suitability for European conditions and continued to order the tools for more diverse uses, although in decreasing numbers as European makers gave more effective competition. By the 1890s, therefore, the various barriers of prejudice, price, lack of demand, in Europe, and lack of export initative in America, were falling, and the result of the interaction of all these forces was the export invasion.

Such an all-embracing explanation can be questioned at many points. Confirmation of some features must wait upon detailed investigation of the machine tool industry in the United States. All that can be claimed for it is that it takes account of more factors, and seems in total more plausible, than the older explanations of American exports which ignored their chronology and explained them by a simple assumption of American superiority.

CHAPTER 5

GREENWOOD AND BATLEY : MARKETS AND PRICES.

In the preceding chapters, the English machine tool industry has been treated very much in aggregate terms. With the exception of some consideration of individual firms in chapter 3, the performance of the industry at Home and abroad, and its structure, has been treated from aggregate sources, and even the evidence presented from the history of individual firms has been treated as helping to build a general picture of the industry and of its growth over the whole period from 1850 to 1914.

In this and the following chapter, by contrast, attention is concentrated on the experience of a single machine tool producer, the engineering firm of Greenwood and Batley of Leeds. Such a concentration makes it possible to answer many questions about the industry which cannot be answered on an aggregate level, questions of the nature of demand for machine tools facing individual firms, of the methods of production, of accounting methods, entrepreneurial behaviour and relationships with other firms and with customers. For reasons of space, several of these questions can be treated only scantily or not at all; an example of the latter is the history of labour relations and the labour force. This chapter concentrates on the sales made by the firm, on the industries to whom the sales were made, and on the prices charged for machine tools. In the next chapter the production process is examined, largely through a study of the causes and effects of changing labour productivity.

I. A short history.

1 Foundation and management.

The firm of Greenwood and Batley was founded in 1856, as a partnership between Thomas Greenwood and John Batley. Thomas Greenwood had been apprenticed to his father, a machine-maker in Gildersome, Yorkshire, had then worked in Kirkstall for the firm of Stephen and Joseph Whitham, and had in 1843 become chief draughtsman to Sir Peter Fairbairn at the Wellington Foundry, Leeds.[1] John Batley had worked with Greenwood at this period, but nothing is known about his earlier life.

The firm continued under the management of Greenwood and Batley until 1873, when Thomas Greenwood died.[2] He was succeeded in the partnership, and in the management of the firm, by his sons George and Arthur, and by his nephew Henry. A fifth partner, also active in the management of the company, was John Henry Wurtsburg, brother-in-law of both Arthur and George, and of Henry Greenwood. Some division of responsibilities seems to have taken place; Arthur Greenwood and Wurtsburg took control of the day-to-day operations of the firm, Henry Greenwood became head of the drawing-office, although Arthur Greenwood, like his father, was responsible for the invention of much of the machinery made by the company, particular in the field of machine tools for the manufacture of armaments. George

1 Victoria County History of Yorkshire, vol. II, "Industries Iron and Hardware", by Llaud Sellers (London:1912) p.400. Thomas Greenwood the elder is listed as a 'machine maker' in Gildersome in E. Baines "History, Directory and Gazetteer of the County of York (David & Charles Reprint Newton Abbot, 1969) Vol. I, p.507.

2 Private information from Dr. Charles Greenwood, great-nephew of Thomas Greenwood.

Greenwood spent at least some of his time as foreign salesman for the company, largely in Europe, but also made trips to the Far East and to Russia. John Batley appears by this time to be playing little part in the management of the partnership.[3]

In 1888 the partnership was dissolved, and the firm became a public limited company. Three outside directors were appointed, and Arthur Greenwood became Chairman and managing director. George and Henry Greenwood and Wurtsburg continued as the other managing directors, while John Batley dropped out of the management, and even of the control of the firm; he did not, unlike the Greenwoods, receive part of the purchase price of the new Company in the form of shares.[4] The three outside directors were almost certainly appointed because of their knowledge of, and contacts with, the most important single customer of the firm, the British government and its military services. Vice-Admiral Philip Colomb had retired from the Navy in 1886, after a distinguished career, particularly in the field of safety at sea and signalling systems. He conducted for Greenwood and Batley negotiations with the Admiralty about the manufacture of the Whitehead torpedo although he does not seem to have been successful in obtaining any orders, as most of the investment of £30,000 was wasted.[5]

3 Private information from Dr. Charles Greenwood, and Memoir of Arthur Greenwood, P.I.M.E., Jan. 1910, p.386.

4 Agreement, dated July 5, 1888 between John Batley, George Greenwood, Arthur Greenwood, Henry Greenwood, and John Henry Wurtsburg, the Vendors, and John Taylor as Trustee for 'a company intended to be incorporated under the name of "Greenwood and Batley Limited". (Document in the possession of the author). Greenwood and Batley, Board Minutes, July 11, 1888. (Minutes in possession of the firm.)

5 The career of Colomb is given in "Who Was Who", 1897-1914 p.150. Information on the Whitehead torpedo from Greenwood and Batley Board Minutes. An obituary of Colomb appeared in 'The Times', 16th October, 1899.

The second outside director was Lieutenant-Colonel Ralph Vivian, who had served in The Scots Guards until his retirement from the Army in 1883; he does not seem to have had particular contacts with the army purchasing departments, and he played little part in the control of the firm.[6] The third director appointed in 1888 was Major-General Edward Micklem, who had been a distinguished Royal Engineer, and had ended his army career in 1887, having been Assistant Adjutant-General of the Engineers. He was also a director of several other companies, at least one of whom lent money to Greenwood and Batley.[7]

After the formation of the limited company in 1888 few changes took place in the management of the company before 1914, except those caused by the deaths of George Greenwood in 1893, Wurtzburg in 1903 and Arthur Greenwood in 1910. They were replaced as directors by employees of the company about whom little information has survived; Arthur Greenwood was replaced as Chairman by Major-General Micklem.[8]

2 Products of the company.

Greenwood and Batley were at their foundation, and remained for much of the period until 1914, general engineers, manufacturing many different types of engineering equipment. In 1908 a writer in the Times Engineering Supplement described them as :

6 "Who Was Who" 1916-1928, p.1076, and Greenwood and Batley Board Minutes.

7 "Who Was Who" 1929-1940, p.937, and Greenwood and Batley Board Minutes.

8 Information from Dr. Charles Greenwood, and from Greenwood and Batley Board Minutes.

> "the most famous of all the Leeds firms,.... They make such a bewildering variety of different things - torpedoes, turbines, electrical plant, cartridges, machinery for silk mills, oil mills, boot sewing, wood-working etc. - that the machine tool department is dwarfed; but it is large, extremely varied, and modern.9

To this list can be added, on the basis of the order books of the firm and the minutes of the meetings of the board of directors, electrical carriages, horseshoes, rifles, and steam engines, and the firm even invested in a number of light railways. Even within the field of machine tools, with which this study is principally concerned, the range of products was very considerable. A list of the machine tools which they manufactured between 1856 and 1900 is given in appendix 5, 1.

The principal pre-occupation of the firm, in its production of machine tools, was with machine tools suitable for use in the armaments industry. However, since they supplied tools not only for the small-arms trade, with its demands for light, special purpose, machine tools, but also the heavy gun makers, whose needs were for the largest and heaviest machine tools, the products of the firm spanned the whole range of machine tools produced during this period, either in this country or abroad. They were among the first makers of milling machines in Great Britain, and also pioneered the use of the capstan lathe. Thomas Greenwood was known as the foremost inventor of machine tools for armaments manufacture in this country, and his successors carried on this innovating tradition, working closely with the arms manufacturers in developing new machine tools.[10]

9 Dr. A. Shadwell, "Engineering Supplement to '<u>The Times</u>' March 4, 1908.

10 The Agreement for the sale of the Assets of the Partnership lists 67 British & Foreign patents held by the Partnership dating from 1875 to 1888, of which 6 refer to armaments machinery, taken out by Arthur and George Greenwood.

Although Greenwood and Batley continued until 1914 to make a number of different products, there are signs of attempts, common throughout the engineering trade at this period, to standardise and to reduce the number of products made. This was particularly difficult in the machine tool trade, because of the tradition of special-purpose manufacturing, and because customers expected their suggestions and needs to be incorporated into the design of their tools, but the firm, in the first decade of this century, began to attempt to produce standard patterns of machine tools, "so that these could be made to stock and early delivery of them given."[11] During the period up to 1900 however, with which these two chapters are largely concerned, standardisation was limited to a few parts which could be easily interchanged, such as lathe beds, and to a policy of making machines for stock; if an order for one machine of a type was received, perhaps four or six would be made, to save the time and expense involved in retooling.

3 Financial history.

Very little is known about the financial history of the company as a whole prior to 1882. Thereafter figures on the profits of the company are given firstly in the share offer prospectus of 1888 and then in the profit and loss accounts, balance sheets, and directors' reports. It is said that Thomas Greenwood and John Batley invested £10,000 in the partnership in 1856, but this seems an extremely high figure, much higher than the initial capital investment in any other machine tool or engineering company; it is also difficult to explain how two working engineers could

11 Greenwood and Batley Board Minutes, March 2, 1911.

have raised such a sum.[12]

The profits of the firm were given in the documents concerning the share offer as an average of £18,329 per year between 1882 and 1885, and an average of £33,256 for the period 1886 to 1888. In spite of these profits, it appears that the main impetus behind the decision of the partnership to dissolve and form a public company was the need for further capital to finance an expansion of the business. As the prospectus of 1888 stated, the initial capital issue of £300,000 would leave a balance of £35,000 after the payment to the partners of the value of the firm, £265,000; this £35,000 was :

> "partly required to carry out additions to the Buildings and Plant, which are already commenced, and are being rapidly proceeded with; and partly for increased working capital, to meet the increased turnover of the firm"13

The initial share issue, and the £35,000 which it raised, soon proved insufficient to provide for the needs of the company, which was engaged on a major rebuilding of its works, and in 1890 a further £44,000 worth of shares was offered to the existing shareholders, although in the event only 1,466 Preference shares of £10 and 1,252 ordinary shares, also of £10 were applied for. Only £5 of each share was called for in 1890, so that the total capital raised was only £8,154.[14]

The only remaining changes in the capital structure of the company came in 1893, when £20,000 of Debentures were

12 F.J. Glover "The Growth of Transport in Leeds" The Leeds Journal, 1956, p.343.

13 Greenwood and Batley Prospectus 1888. The First Issue was of £80,000 Debentures, 8000 £10 7% Cumullative Preference Shares and 14,000 £10 ordinary shares, the Managing Directo taking "one third of the Debentures and of each class of shares in Part Payment."

14 The Board decided to make the issue on May 6, 1890 and th results were reported on August 29, 1890. Greenwood & Batley Board minutes for those dates.

issude to the bank as security for the large overdraft which they had granted to the company,[15] in 1899 when further calls were authorised on the issue of 1890, and in 1909 when a further £2 was called for on the shares issued in 1890, apparently to meet a need for working capital.[16]

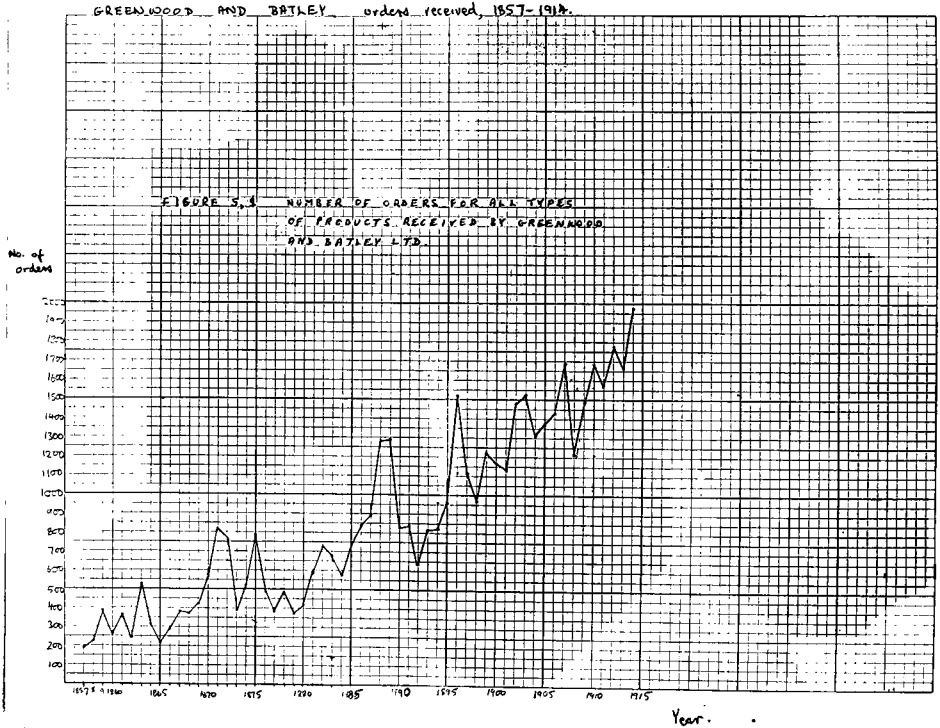
The expansion of the works, and the flotation of the company which the need for finance for expansion demanded, both proved to have been based on incorrect assumptions of the course of future demand for the products of Greenwood and Batley. Figure 5, 1, shows the number of orders received by Greenwood and Batley during the period from 1857 to 1914; (it would of course be much more satisfactory to have sales figures, but the labour of compiling such figures from the order books ruled out such a calculation). In the light of the steady but slow growth in orders up to 1888 it is surprising that such heavy investment should have been undertaken at this period, and it is unclear on what evidence an expectation of the type of future growth for which this expansion could cater was based. The total value of the firm in 1888 was, according to the valuation, £265,000, yet capital expenditure undertaken during the financial years 1888-1891 was £104,149, and the burden which this placed on the firm was increased by the dislocation caused in the works by the rebuilding operations, particularly the expensive construction of a link to a nearby railway.[17]

15 Greenwood and Batley Board Minutes, May 19, 1893

16 Greenwood and Batley Board Minutes, June 9, 1899, July 3, 1908. It is possible that no calls were actually made in 19[illegible] in the prospectus of 1888.

17 Valuation of £265,000 was given [illegible] Expenditure on alterations was given to the Board on June 15, 1891. One May 6, 1890 the Chairman had reported to the Board that "The inconvenience caused by the work going on had disorganised the workshops and greatly increased the difficulty of moving work from one shop to another and also the cost of turning it out"

~~GRAPH I.~~


GREENWOOD AND BAILEY orders received, 1857-1918.
FIGURE 5.1 NUMBER OF ORDERS FOR ALL TYPES OF PRODUCTS RECEIVED BY GREENWOOD AND BAILEY LTD.
No. of orders
Year.

The result, therefore, of the conversion of Greenwood and Batley to a public company, and of the expansion of capacity undertaken at the time, was to provide the new Company with a burden of some £310,000 nominal of share capital, on which dividends had to be paid, and a large debt to the Company's bankers, who financed the gap between the approximately £40,000 raised by the share issue and the capital expenditure of over £100,000 undertaken by the company. Further, the need for working capital was increased by the extension of capacity, both because of an expansion in the clerical and other overhead costs, and also because expansion was concentrated in departments of the works engaged in production of goods, payment for which might be long delayed. The expansion was in fact concentrated in the heavy tool shop, the torpedo plant, and the cartridge department. The first of these branches was engaged in making the larger tools, where manufacture could take a year or more, during which time the expenditure had to be financed by the firm; there was apparently no system of part-payment before delivery. In the cartridge and torpedo departments, the firm was catering almost entirely for government orders, on which payment was often long delayed, and was in a market situation much like that described by Mr. Trebilcock as existing in the cordite industry. That is, the government attempted, by placing orders with selected companies, to persuade them to instal machinery to make a particular type of arms; once the machinery was installed, and the first order completed, no further orders would be placed, all peacetime demand being supplied by the government factories, the government reasoning that the private firm would be unwilling to scrap its investment in new machinery, which would therefore be available for use in time of emergency need.

The expansion undertaken by Greenwood and Batley around 1890 appears, therefore, to have been misguided. While in March 1889 the company had a credit balance with their bankers of £30,362, by the following year it owed £12,072, and in 1891 £52,524. The debt continued to increase, and some Consols owned by the company were required to be sold; the debt however increased to £57,602 by June 1892.[18] In 1893 £20,000 worth of debentures were deposited with the bank as security for the loan into which the overdraft had been converted, but a further overdraft had to be obtained soon afterwards. In this situation, it is clear that two policies were open to the directors, retrenchment and the writing-off of the unproductive investment, or further expansion in the search for some profitable occupatio for the works. The managing directors chose the latter course, and during the period from 1893 to 1899 undertook a series of speculative investments, most of them unsuccessfu while trying to pacify the London directors, Nicklen, Colomb and Vivian, with minor economies in administration. In 1893 Arthur Greenwood was dissuaded with difficulty from taking up a concession to establish a light railway in Mandalay.[19] In 1896 :

> "By an arrangement with a coach builder in Leeds a Wagonette has been placed at the company's disposal, and it was intended to see whether an electrical motor car could be made which would be a success"[20]

a venture which ended in a substantial loss ten years later. In 1898 the company entered another new field, with the formation of the English de Laval Steam Turbine Co.

18 Greenwood and Batley, Balance Sheets, 1889, 1890, 1891. Board Minutes, June 10, 1892.

19 Greenwood and Batley Board Minutes Feb. 10, 1893

20 Greenwood and Batley Board Minutes Dec. 2, 1896

The London directors initially refused to agree to the investment, proposed by Arthur Greenwood, of £30,000,

> "Bearing in mind the increase of net earnings which would be needed to render it remunerative, and the fact that the large expenditure on capital account which was incurred in the early years of the company has not (so far as we can judge) proportionately increased its earning power, while, in order to fill the works with remunerative employment a much larger yearly amount of orders has been rendered necessary".

In spite of this refusal Greenwood and Batley made large advances to the new de Laval Company, and in 1903 it was necessary for them to return to Greenwood's initial proposal, and effectively to take-over the de Laval Company as a subsidiary.[21] During the course of these negotiations, Greenwood and Batley were also investing heavily in a light railway in Lancashire, another investment producing an extremely low rate of return.[22]

21 Greenwood and Batley Board Minutes March 28, 1898, June 6, 1898, Dec. 8, 1898, June 9, 1899. The de Laval Company was then frequently discussed by the Board, the original proposal being accepted in parts on Feb. 6, June 19, and Dec. 8 1903.

22 The application to promote a railway was reported to the Board on May 13, 1898. The subject was discussed on Nov. 3, 1898, and July 5, 1902, when it was reported that "The Company were engaged in designing a small self-contained Electrical Train" for use on branch lines, on June 19, 1903, on March 10, 1904, on June 15, 1905; on January 19, 1909 the Chairman proposed that the railway, the Colne and Trawden light railway, should be disposed of; on March 8, 1910 it was said the "it might prove a considerable loss". The railway was finally sold to Colne Corporation in 1914, the sum paid to Greenwood and Batley being £9,367.12.11d.

Apart from these speculative ventures, which have the air of desperate attempts by the managing directors to regain some of the former prosperity of the company, the internal financial management of the firm appears to have been very loosely conducted. Large credits were given to weak customers, particularly those, like the Colonial Ammunition Company, in which Arthur Greenwood was personally involved.[23] In 1893 the auditors reported that the financial affairs of the company were conducted in a way which made it impossible to keep accurate records of sales and purchases, largely because of a long-standing practice of paying for supplies by means of cheques received from customers, without passing the cheques through Greenwood and Batley's account.[24] It was also discovered in 1893 that the managing directors had habitually borrowed from the company in anticipation of their salaries; no exact sums are given in the minutes of the Board of Directors, but the Chairman in particular appears to have been a substantial debtor.[25] In 1894 he transferred to Greenwood and Batley shares in the Chelsea Electricity Company with a paper value of £2,765, to 'reduce his indebtedness' to Greenwood and Batley, but since the Chelsea Electricity Company was a moribund concern, the annual general meeting of Greenwood and Batley in 1896 ordered their Chairman to take back the shares and pay cash instead;[26] Arthur Greenwood and J.H. Wurtsburg still appeared as debtors of the company in 1899, though for comparatively small amounts.[27]

23 Board Minutes, June 26, 1900

24 Board Minutes, June 28, 1893

25 Board Minutes, June 28, 1893, May 25, 1894

26 Board Minutes July 9, 1894, July 28, 1896

27 Board Minutes December 15, 1899.

The combined result of the financial mismanagement and unwise investment policies of the company, together with the apparent instability of demand for their products during the period from 1890 to 1914, is reflected in the dividend record of the firm, given in Table 5, 1, below.

Year	£10 preference shares	£10 ordinary shares
1889	7%	10%
1890	7%	10%
1891	7%	nil
1892	7%	nil
1893	7%	nil
1894	nil	nil
1895	nil	nil
1896	13½%	nil
1897	17½%	2½%
1898	7%	nil
1899	7%	3%
1900	7%	2½%
1901	7%	5%
1902	7%	5%
1903	7%	4%
1904	7%	5%
1905	7%	6%
1906	7%	5%
1907	7%	4%
1908	7%	4%
1909	7%	nil
1910	7%	nil
1911	7%	nil
1912	7%	nil
1913	7%	nil
1914	7%	5%

TABLE 5, 1. Dividend payments on the share capital of Greenwood and Batley, 1889-1914, expressed as % of the nominal value of the shares.

Further measures of the financial success or failure of the company would be the rate of return on the capital

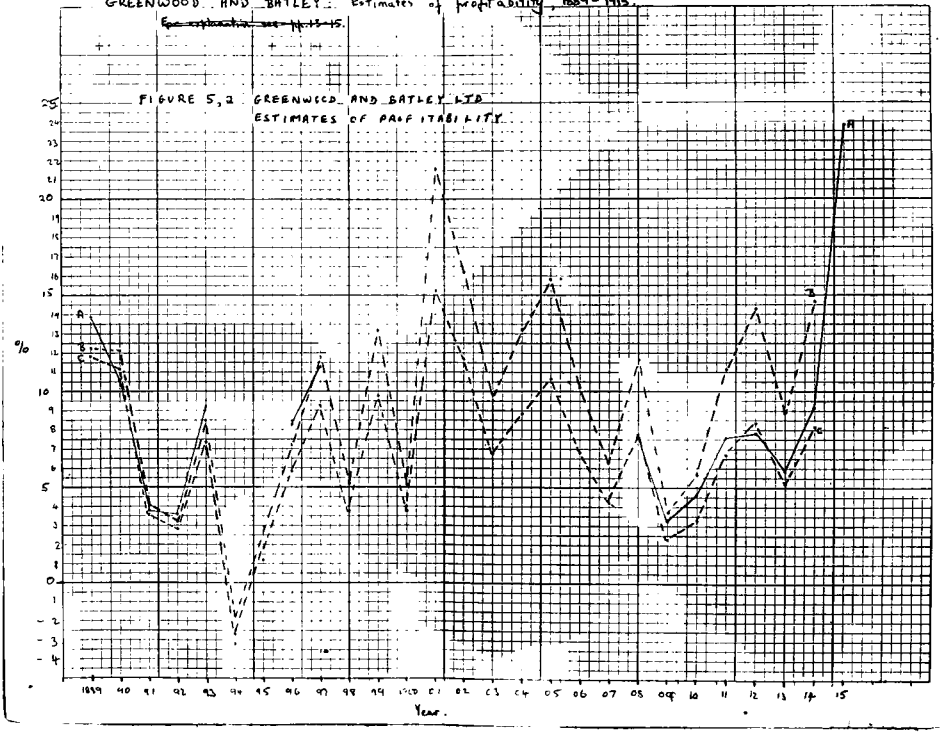
employed, or alternatively the trading profit as a proportion of turnover. In the case of rate of return on capital complications are introduced into the calculation by the practice employed in allowing for depreciation of the capital stock. In common with many firms of this period, Greenwood and Batley adopted a policy of varying the depreciation allowance according to the trading profit, reducing the amount written off in the trading profit seemed low, as in 1895, when nothing was written off the value of capital equipment. In figure 5, 2, therefore, two methods have been adopted of dealing with depreciation. In the first, the result of the calculations being line B on the graph, a figure of 5% per year has been written off, regardless of the depreciation allowed by the firm, while in the second method, line C, the mean of the depreciation allowed by the firm over the whole period has been calculated, and applied to the figures for each year. Thirdly as a measure of profitability, line A shows trading profit as a percentage of turnover. All these measures are extremely crude, but together, as shown in figure 5, 2, they do give some indication of the profitability and efficiency of the firm. They do at least demonstrate the truth of the comment in the Financial Mail of July 4, 1914, that :

> "Greenwood and Batley have a splendid name for quality. It is one of the best engineering works in Leeds. Nevertheless, its record as a limited company has been simply disastrous. Over-capitalisation and bad management are probably responsible for the fact that no ordinary dividends have been paid since 4% was distributed in 1908.... It seems to the ordinary outsider that Greenwood and Batley with its magnificent reputation should do far better. It was over-capitalised at the start and the finances have never been carefully attended to. None of the securities are satisfactory"[28]

28 'Financial Mail', July 4, 1914. Press-cutting among G. & B. records.

Figure 5,2.

GREENWOOD AND BATLEY. Estimates of profitability, 1889-1915.



4 The technical standing of Greenwood and Batley in the machine tool industry.

Even in an hostile article commenting on two decades of financial ineptitude and failure in the management of Greenwood and Batley, the Financial Mail could still describe it as 'one of the best engineering works in Leeds'. This raises the question of the standing of Greenwood and Batley within the engineering industry, and particularly within the machine tool industry. To establish the position of the firm vis-a-vis other makers of machine tools is particularly important in order to assess the value of the analysis of the market situation facing Greenwood and Batley, and of its internal organisation and production, which follows in this and the succeeding chapter. If Greenwood and Batley can, throughout the period, be considered to be one of the 'best-practice' machine tool plants, then it is possible to utilise the evidence of its organisation and its production as a guide to the experience of other 'best-practice' firms in the industry, and, through them, to the speed of innovation and changing methods in the machine tool industry as a whole. The use of evidence from Greenwood and Batley alone is subject to the criticisms, made at length in chapter 3, of the use of evidence from what may be exceptional firms. It is not claimed, however, that Greenwood and Batley is typical of the industry, but rather that the evidence suggests that it held, throughout the period from 1856 to 1900, a place among the leading firms, and was not exceptional either in growing faster than other firms or in falling behind its competitors. Greenwood and Batley, in fact, progressed as did the rest of the industry, and, in some particular respects, can therefore be regarded as representing that progress.

To support this claim is particularly difficult in view of the paucity of quantitative data on the operations of other firms, either 'best-practice' or less advanced in their technical or commercial progress. Greenwood and Batley's experiences can therefore not be compared directly with those of other firms. It is however possible to gain some idea of the place of the firm within the machine tool industry by studying the comments of unbiased observers, particularly those engineers who wrote the official reports on the international exhibitions. Although these observers were largely concerned, as was suggested in the last chapter, with technical rather than commercial competence, their reports can be a guide to the relative standing of the major English machine tool makers who sent tools to these exhibitio

Greenwood and Batley's first appearance as an exhibitor at a major international exhibition was at the London Exhibition of 1862, at which they showed a machine with circular cutters for machining rifle muskets. They were commended for this machine by D. K. Clark in his extensive work on "The Exhibited Machinery of 1862", and the Jury Reports of the Exhibition mentioned the "great ingenuity and originality of Greenwood and Batley".[29] At the 1867 Paris Exhibition, at which Britain was generally under-represented in machine tools, owing, according to the British Commissioner, John Anderson, to the fact the "toolmakers had been busy for many months preceding the opening of the exhibition, and had been unable, frequently, to fill regular orders", Greenwood and Batley did not show any machine tools. This fact was commented on, by John Anderson, who linked their absence with that of Nasmyth, Hulse, Smith, Beacock

29 London Exhibition [illegible]. Jury Reports on Class VII, 3, p. 5 and D.K. Clark "The Exhibited Machinery of 1862" (London: 1864) [illegible] 130

and Tannett, and Fairbairn, all of them well known makers of machine tools.[30] The next major exhibition at which Greenwood and Batley exhibited was that in Philadelphia in 1876, at which the firm received an award for a Bolt Heading Machine; this was in fact one of the few British machine tools sent to the exhibition, perhaps reflecting the unwillingness of British manufacturers in general to attempt to sell in the protected American market.[31]

During the next decade Greenwood and Batley's tools do not seem to have attracted any attention at the international exhibitions, but in 1880 the firm received a silver prise for cartridge-making machinery, and a diploma for twist drill chucks and cutters, at the Melbourne Exhibition of that year.[32] In 1889 other British makers, Hulse, Selig Sonnenthal and Smith and Coventry, were mentioned by the American Commissione to the Exhibition in Paris, but most space was given to a description of a large engine lathe made by Greenwood and Batley for Schneider and Co. of Creusot :

> "These builders (Greenwood and Batley) have made many large tools for the arsenals and other government institutions. They do not confine themselves exclusivel to machine tools, but this line of work is the most important of their productions. The grandest machine in this class at the Exposition was, without doubt, the large lathe just built for Schneider and Co., of Creusot

30 Report to Parliament on the Paris Exhibition of 1867, (P.P 1867-8, XXI, Pt. II, 341), Report on Machine Tools by John Anderson, pp.702,722.

31 Reports of Philadelphia International Exhibition of 1876, (P.P. 1876, XXXIV, 1). Report on Machines and Tools for working Metal, Wood and Stone, by John Anderson, p.310 and Reports Volume III, (P.P. 1877, XXXVI, 1) giving list of Awards in group 21.

32 Report of Royal Commission for Melbourne Exhibition of 18f (P.P. 1882, XXVIII, 1) pp.471, 476.

> "by Greenwood and Batley.... Not the least remarkable thing in connection with this tool is the shortness of the time taken in its design and execution. A consideration of the following statement conveys some idea of the facilities possessed by this house for turning out large work."

There followed a description of the production, and of the dimensions of this machine.[53]

In 1900, at another Paris exhibition, Greenwood and Batley was linked with Whitworth, Muir, Hulse, Shanks and Buckton, all well-known tool makers, as "conspicuous by their absence",[54] but by this time both the lure of international exhibitions, and Greenwood and Batley's reputation, was diminishing, and the only other comment on their activities from an impartial observer, writing in 1910, seems to confirm this. In 1909 and 1910 G.L. Carden's consular report on the engineering works of Europe was published by the U.S. government. Greenwood and Batley are mentioned only three times in the reports, although other British firms are prominent. Two mentions concern the Italian Government arms works, at Terni which was fitted out with nearly 900 tools 'in the early eighties' by Greenwood and Batley, where "much of the... equipment is now old", and that at Rome where Carden commented :

> "Greenwood and Batley of Leeds have supplied several universal spiral gear cutters. This firm, I understand, did considerable business with the Italian Government works in previous years, at a time when the Leeds house was regarded as one of the first in the building

53 Report of U.S. Commissioners to the Paris Exhibition of 1889, Vol. III, "Machine Tools" by John H. Barr (Exec. Docs., House of Representatives, 1889-90, vol 40 Washington: 1893) pp.552-3-4.

54 Report of the Royal Commission to the Paris Exhibition of 1900. (P.P. 1901, XXXI, 1). Report by C.W. Burton, British Juror in Class 22, Machine Tools, p.568.

"of arsenal tools. The Greenwood and Batley tools present are not of recent make."35

These impressions of the standing of Greenwood and Batley culled from exhibition reports, undoubtedly do not give a very complete picture of the standing of Greenwood and Batley within the machine tool industry. The products of the firm were also mentioned often in the technical journals serving the industry, giving an impression of innovative activity, but no very concrete evidence can be gained from these sources. In general, all that can be said is that Greenwood and Batley were ranked, on a number of occasions which have been quoted, with the acknowledged leaders of the machine tool industry, Whitworth, Nasmyth and their successors. Therefore, the evidence which is available suggests that Greenwood and Batley can, at least for the period before 1900, be regarded as a 'best-practice' firm, although it seems likely that their reputation and standing declined during the early years of this century.

Sources and method.

The sources available on the work of Greenwood and Batley make it possible to reconstruct in considerable detail many aspects of the history of the firm and of its production of machine tools. There are however a number of features of the records, of which a full list is given in appendix 2, 2, which affect the nature of the analysis, and it is the object of this section to describe the records which have been used and to indicate the ways in which they can illuminate the history of the firm.

35 ... Carden "Machine Tool Trade in Italy" (Washington: 1910) pp.168,169.

The major sources which have been used in the analysis in this and the following chapter are the order books, the time ledgers, the directors' minutes, the balance sheets and the profit and loss accounts of the firm. In addition, the letter books, catalogues and press cuttings have been studied, and information from them has been used on a number of occasions. No attempt has been made to use the ledgers relating to particular sections of the works or to the manufacture of sectional parts, nor have the patent specifications, photographs, cash and cheque records, and carriers' delivery records been studied in any detail.

The order books, for which an unbroken series from 1856 to 1920 are available for study, provide the following information :

1. Order number.
2. Member of the firm who obtained the order.
3. The date on which the order was received.
4. The date on which the order was dispatched to the customer
5. The name and address of the customer, or of the agent to whom the order was consigned.
6. A description of the machine or machines ordered.
7. The number of machines in the order.
8. The price of the order.
9. The number of the photograph of the machine ordered.
10. The catalogue number of the machine ordered.
11. The number of the order from the dispatch book.

The cost books, which are available in an unbroken run from 1855 to the present day, give, for each order :

1. The date of starting work on the order.
2. The time worked each day on the order by each of five categories of worker.
3. The wage rate of each of those categories of worker.
4. The total cost of labour on the order.
5. The 'management cost' or overhead cost.
6. The piecework cost.
7. The cost and weight of each metal input.
8. The net and gross weights of the order when dispatched.
9. The cost of any sectional parts used in manufacture.
10. The profit or loss on the order.
11. The date of finishing work on the order.

The directors' minutes, available for the period from the foundation of the limited company in 1888, and the balance sheets and profit and loss accounts for the same period, provide information on the financial affairs and the general policy of the firm.

Greenwood and Batley were, from their foundation in 1856, general engineers. The focus of this study is, however, one segment of the engineering industry, the manufacture of machine tools, and in order to utilise the records of Greenwood and Batley for this study it was necessary to extract from the records all information relevant to the production of machine tools. The order and time ledgers were therefore searched, and information on each order for machine tools was recorded over the period from 1856 to 1900. The following pieces of information were recorded for each such order.

1. The order number.
2. The date of receipt of the order.
3. The date of dispatch of the order to the customer.
4. The name and address of the customer.
5. The name and address of the agent, if this was given.
6. The price of the order.
7. The description of the machine ordered.
8. The number of machines comprising the order. (Machines of different types were given, by the firm, separate order numbers. Thus a number larger than one here will indicate an order for more than one machine of the same description).
9. The date of beginning work on the order.
10. The total cost of labour on the order.
11. The total 'management cost' of the order.
12. The net weight of the completed order.
13. The total cost of the order.
14. The cost of piecework labour for the order.
15-19. The hours of labour on the order by five categories of labourer. (The categories were : Boys, Planers and Borers, Turners and Fitters, Boy Joiners, and Men Joiners

It will be apparent that some of the information provided in the order and time ledgers was not recorded, and was therefore not available for use in the analysis. The catalogue and photograph number of the machine was not thought to be of use in an analysis largely concerned with the economic history of the firm. The name of the member of the firm obtaining the order was not given in many cases, and such information did not in any case seem very susceptible of quantitative analysis. The number in the dispatch book was simply an identification number and thus duplicated the

order number already recorded. The date of finishing work did not normally differ by more than a few days from the date of dispatch, and was therefore not included. The profit or loss could be calculated from the information recorded and its inclusion as a separate item was therefore unnecessar The gross weight of the order, although significant in transport costs and, in some export markets, tariff charges, seemed of less value than the net weight, and was therefore excluded.

Of the remaining items, the total of metal inputs and inputs of sectional parts can be calculated as a residual when labour, management and piecework expenses are deducted from total cost; although it might have been of interest to have had these pieces of information in more detail, the effort required in recording them, when up to ten different metals and as many sectional parts could be used on one order, would have seriously hampered the data collection, and added little to the final analysis. Note was however taken separately of the cost of the different metals employed. The final omission, that of the hours worked on the order during each day, can be justified also on the grounds of the effort involved in recording the information, and the probability that it would add little to the analysis, since the length of the period of manufactur and the total hours worked, had been recorded for each other.

A further omission was that of information on the period after 1900. It would have been desirable to have carried the analysis of the production of Greenwood and Batley up to the terminal date of this study, 1914. During the

course of data collection, however, it became clear that during the last decade of the nineteenth century the firm was increasingly adopting a system of bulk manufacture of sectional parts, in particular for the machines which it built in some numbers. The manufacture of these sectional parts necessarily involved some labour cost, and 'Management cost' which was included within the 'sectional parts' entry for each order recorded in the time ledger. As the manufacture of sectional parts became more common, therefore, the proportion of final cost attributable to 'sectional parts' rose, producing an apparent reduction in the 'labour cost' element in final cost. This reduction was apparent rather than real, being the result of the system of accounting within the works. It would theoretically be possible, through the use of the sectional parts ledgers, to trace each part used and to add the labour cost element in its production to the labour cost element in the final machine (and similarly with the 'management cost') but this would be so time consuming as to be impossible within the scope of this analysis. It was therefore decided to conclude the recording of data in 1900, before this source of bias became too great, and additionally before a change in accounting practice in the firm reduced the amount of information given in the time ledgers. The order books were not affected by these changes, and it would thus have been possible to continue recording the information from them, but it seemed more sensible to keep the final data set consistent in the amount of information it contained, and to conclude the recording of orders in 1900 also.

A number of conventions were established in the course of recording the data from the order and cost books of the firm.

Broadly, they are consistent with the attitude that, if the data was ambiguous in some way, it should be treated as missing, rather than recorded with a probability that it would be misleading. Thus in the case where an order was for a number of machines, which were completed and dispatched at different dates, then the date of dispatch would be omitted, unless the dates were very close together. The adoption of conventions of this kind, and the inevitable omissions from the original records, together with the necessary omission of such data as price for a machine made by Greenwood and Batley for its own use, resulted in a large amount of missing data. Data of some kind was found to be missing in 2,526 orders out of a total of 4,961 orders which were recorded. The problem of missing data is of course very common in historical studies, and indeed in all studies in which the data is taken over from a source not under the control of the researcher. It is possible to utilise techniques which have been established to deal with such problems, principally by interpolation of results on the basis of mean values found in the data which one does have, sometimes with associated probabilities. Such techniques have not been used in this study, for a number of reasons. Firstly, there is no warrant for assuming that missing values are distributed in the same way as those that are available. Secondly the sample size of the set of entirely correct records, 2,435, is very large by the standards of most economic studies, and it is unlikely that much greater accuracy could be achieved by the interpolation of values in the remaining records, while the effort involved in doing so would be very great. Thirdly, it must be emphasised that,

for a number of variables used in the analysis, the number of missing records is much less than 2,566, and in some cases there is no missing data; for instance number of machines in the order, and the machine type, are known in every case, and in only two cases are the name and address of the customer or agent omitted. The actual number of cases of missing data for each variable are given in appendix 3. Thus for analysis of many of the variables, the problem of missing data is not acute, and can safely be ignored. It should however be noted that, for this reason, the sample sizes quoted in the analysis that follows may differ according to the variables that are being analysed.

The actual method of recording and analysis was to record the data, coding where necessary the information originally in non-numerical form, on data recording sheets. The data was then punched onto paper tape or cards, and a number of checks for accuracy and consistency were applied and the errors thus discovered were eliminated. The corrected data was transferred onto magnetic tape for analysis using a computer. Analysis was carried out largely through specially written programs but partly by the use of statistical routines supplied by the Social Research Centre at the University of Michigan, and, as aids to the use of the I.B.M. 360/65 computer at University College, London, by the University of California (the Biomedical Programs) and I.B.M. Ltd. (the Scientific Subroutine programs).

One further methodological point is of considerable importance to the analysis that follows, and must be considered at some length. The method of data collection

was to extract from the records of Greenwood and Batley all information relevant to the production of machine tools. It may be argued that this is unjustifible, because the work of an industrial firm is an integrated process, and that it can make no sense to abstract from that integrated process one sector for separate analysis. Furthermore, to do so is to discard a great deal of material, and to make it impossible to see the direction in which the firm as a whole is moving; factors in the production of some other segment of the production of the firm may affect its organisation and policy in ways which rebound on machine tool production.

More concretely, it could be argued that the decision to look only at machine tools makes it impossible to consider such variables as the rate of introduction of new machinery, or capital expenditure generally, since there is no way of allocating such expenditure, or such new machines, between different sectors of the firm. On a wider scale, it could be argued that a sector of a firm like Greenwood and Batley, in which machine tool production is only one of a number of activities, cannot be compared with a firm making only machine tools, so that the experience of machine tool production by Greenwood and Batley may not reflect the experience of the industry as a whole. Greenwood and Batley could, for instance, set losses on their machine tools off against profits on their cartridges or horseshoes, and thus survive a period of losses which would have bankrupted a firm making only machine tools.

These objections are all, in theory, extremely persuasive. A number of justifications can, however, be

adduced for the procedure which has been adopted. Firstly the firm of Greenwood and Batley organised its production so that one sector was kept separate from other sectors. The works were physically divided into 'shops' which concentrated on different products. When bonus schemes were introduced, they were based on the performance of the individual departments, of which the machine tool department was one, and when reports were given to the directors they were given department by department. Thus in practice machine tool production was separated from the other activities of the firm, and there is no sign in the directors' minutes of any policy of regarding the firm as an integrated whole; indeed it can be argued that the policy of separate departments prevented an efficient use of the resources of the firm. Secondly, the objection that it is impossible to allocate capital expenditure to individual departments is valid; however, no information on capital expenditure by the firm is available until 1889, so that this objection has no force against the isolation of machine tool production up to that date. After 1889 the objection has more force, but it is arguable that the advantages to be gained by looking at capital expenditure by the firm as a whole are outweighed by the advantages of the method of isolating machine tools that has been applied. The capital cost element in the cost of each item was estimated by the firm, so that in the analysis of individual costs capital expenditure can be accounted for, if rather roughly. As to aggregate capital expenditure, and one of its components, the introduction of new machinery, it is doubtful whether its analysis would make sense, simply because of the lack of homogeneity in the products of the firm. Thus it is impossible to assess the effects of any one piece of capital expenditure without

knowing its exact function, and the effect on production that it has, and the compilation of statistics of aggregate expenditure will measure not some change in the productive potential of the firm but rather, if it measures anything, simply the amount of capital which the firm has available for new capital expenditure. In other words, the gain in information caused by the ability, when considering the firm as a whole, to look at capital expenditure as a whole, is more apparent than real; any analysis of its effects has to break down the firm into units, which is exactly what the procedure being justified does. Thirdly it has been shown that many firms in the machine tool industry were similar to Greenwood and Batley in that machine tool production was only one of their interests. Further, the fact that such firms co-existed with specialised machine tool firms in the market must show that the cost structures faced by both types were similar and that at least in terms of production costs and ability to penetrate the market they can be compared. Finally, and most generally, the lack of homogeneity in the products of Greenwood and Batley make it essential, in any analysis of production, markets, innovation, or productivity to separate one activity from another, as far as is possible within the limitations of the data. There is no logic in combining as one unit for analysis the production of horseshoes with the production of milling machines; the problem of quality changes, the assessment of changing output, the cost of inputs, contain enough difficulties when only one sector is considered, without attempting to lump together sectors which have little in common beyond their location under adjacent roofs.

III. Demand conditions

Greenwood and Batley sold machine tools to 653 customers during the forty-five years between 1856 and 1900. In addition, a number of tools were sold through agents, so that the ultimate destination of the tool is not discoverable. These 653 customers ranged geographically from Leeds to Japan, and industrially from the Chinese Imperial Mint to the Ordnance Store of the Tower of London. Since machine tools are producer's goods, bought to manufacture some other metal product, the total demand for machine tools made by Greenwood and Batley was composed of the various demands from disparate industries; these in their turn were created by the demands for metal goods which these industries were facing. To examine the demand for machine tools from Greenwood and Batley it is necessary, therefore to examine the conditions in the various major markets in which the machine tools were sold.

The most obvious distinction that can be made between customers of Greenwood and Batley is that between customers in the British Isles and customers overseas. Greenwood and Batley were extremely successful in selling their machine tools in export markets. Their first such sale was in April 1857, when Lancelot Kirkup and Co., of St. Petersburg placed an order for a surfacing and polishing lathe worth £155. Thereafter machine tools were exported by the firm in every year except 1865. Table 5, 3, shows the total sales of machine tools to each foreign country over the whole period with which this study is concerned, and table 5, 4, shows the sales year by year to the major foreign markets. It is apparent that the demand from abroad for machine tools, both in total and from individual countries, was subject to severe fluctuations, as can be seen in figure 5, 3, a

Country of Destination	No. of machines Sold	Value of Machines Sold
India	114	£ 10,027
South Africa	32	5,015
Australia	11	1,160
Canada	6	565
Hongkong	7	1,153
New Zealand	9	2,323
Malta	3	255
United States of America	5	404
Russia	1,591	156,508
Japan	101	15,822
France	107	11,275
Germany	41	8,200
Italy	285	21,127
Switzerland	77	6,754
Austria	650	35,969
Belgium	91	9,078
Czechoslovakia	2	108
Spain	94	15,355
Portugal	8	1,670
Sweden	17	1,882
Turkey	83	10,650
Denmark	14	1,009
Norway	16	1,175
Brazil	32	4,114
Hungary	29	2,280
Finland	3	455
China	178	28,865
Argentina	75	3,197
Honolulu	1	135
Uruguay	1	35
Morocco	1	90
Egypt	10	1,434
Afghanistan	37	5,166

TABLE 5, 3. Greenwood and Batley Ltd. Total orders from each foreign country, 1856-1900.

Note : 1. This table refers only to machines sold for which both price and cost are known.

2. Current prices.

Year	Russia	Japan	Italy	Austria	Spain	China	All Other
1856							
57	31				[illegible]		1,655
58					110		1,417
59							1,389
60							96
61					643		945
62	262		145		40		1,059
63	930						235
64							2,522
65							
66				677			1,469
67	228			9,864	1,280		2,292
68	1,430			7,573	410		1,910
69	2,767		1,080	1,550			1,494
70	205			1,757	80		6,712
71	34,232	270	600	[illegible]			[illegible]
72	1,312	1,200	115	[illegible]			[illegible]
73	2,146			6,232			775
74	2,133		230			2,795	2,161
75	1,310		375	1,475	1,[illegible]	781	1,749
76	580						390
77	2,701						410
78	305	1,235			2,365		360
79	5,385				75		35
80	36	95					9,903
81				110	580		[illegible]
82	2,300			245			5,136
83			935				3,388
84	855		345				[illegible]
85				740		132	[illegible]
86	5,060		70			[illegible]	[illegible]
87		2,[illegible]	2,704			[illegible]	[illegible]
88		340	12,820				300
89	405	83	473	[illegible]	6,702	7,440	5,436
90	1,651			[illegible]		[illegible]	1,735
91	33,953						215
92	3,205	75	754				746
93	5,127				401	75	1,[illegible]
94	5,976	104			560	2,[illegible]	1,372
95	10,787	132		155	216	[illegible]	4,230
96	6,773	[illegible]			[illegible]	[illegible]	656
97	[illegible]	55	185				2,065
98	14,[illegible]	1,180	296				[illegible]
99	3,[illegible]	140					[illegible]
1900		420					31

TABLE 5, 4. Greenwood and [illegible]tley [illegible]td., Value of foreign orders of machine tools, 1856-1900 by selected countries and by year.

Table 5, 4, continued :

Note : Figures are in £, in current prices.
Blank signifies no sale in that year.
Individual countries are those with total sales greater than £15,000, see table 5, 3.

Ch 6 - 3 Figure 2

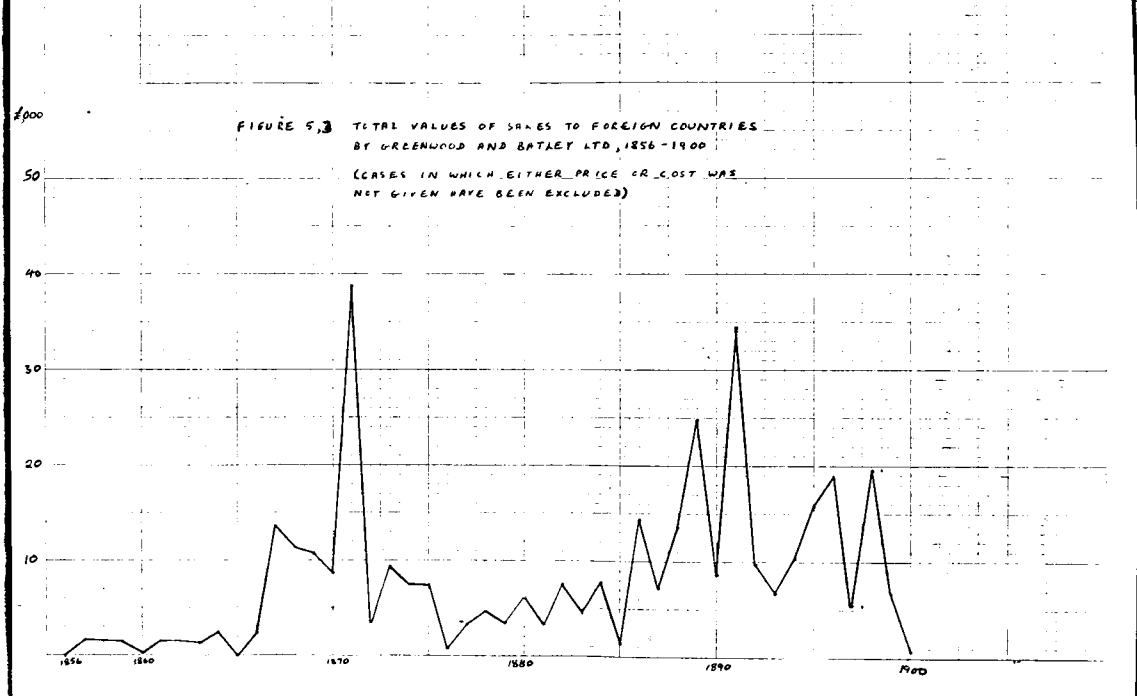
GREENWOOD AND BATLEY Value of sales to foreign countries, 1856-1900 (Based on Table 3)

£'000

£'000

FIGURE 5,3 TOTAL VALUES OF SALES TO FOREIGN COUNTRIES BY GREENWOOD AND BATLEY LTD, 1856-1900

(CASES IN WHICH EITHER PRICE OR COST WAS NOT GIVEN HAVE BEEN EXCLUDED)



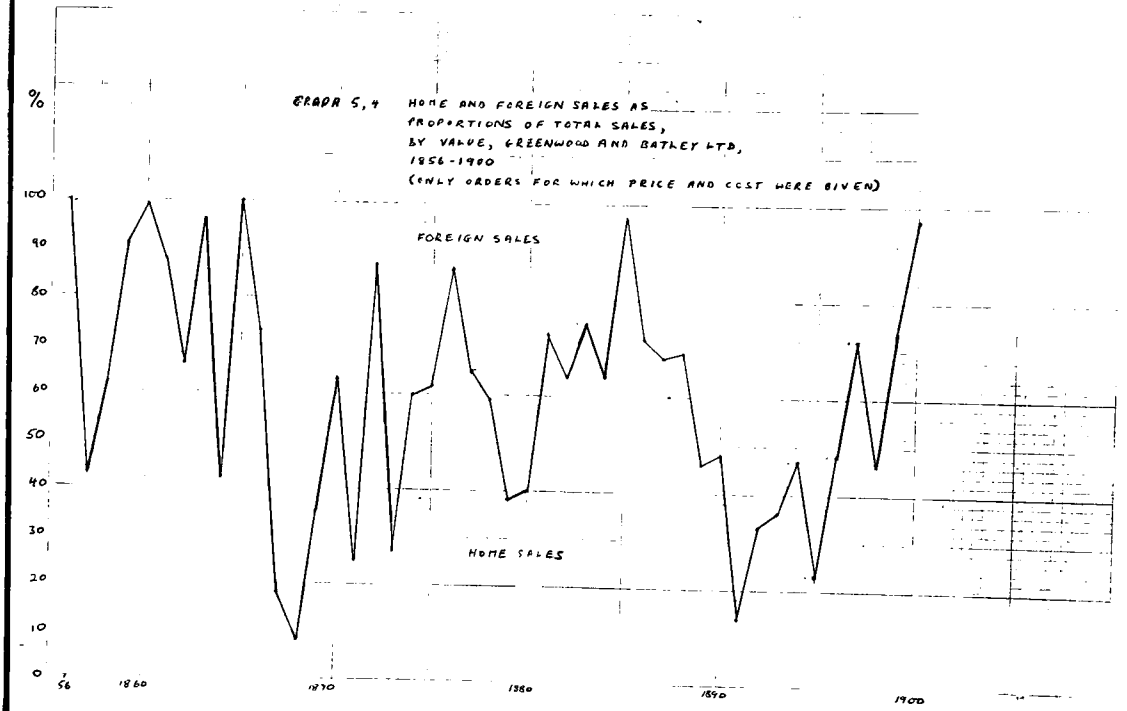


FIGURE 5,4 HOME AND FOREIGN SALES AS PROPORTIONS OF TOTAL SALES, BY VALUE, GREENWOOD AND BATLEY LTD, 1856-1900 (ONLY ORDERS FOR WHICH PRICE AND COST WERE GIVEN)

histogram showing the yearly value of foreign orders to the firm. Nevertheless, as table 5, 5, shows, foreign demand was, throughout the period, an important component of total demand for the firm, and in fact made up about 40% of output over the period. Figure 5, 4, shows the year by year percentage distribution between home and foreign orders.

The firm was also successful in selling their machine tools throughout Great Britain, and there is no sign that they were, at any period, restricted to the area around Leeds. In the distribution of orders between the major industrial regions in this country, shown in table 5, 6, London predominated, because of the high volume of orders from the arsenals and arms factories around London, but demand was otherwise spread widely through the country, and reflected the industrial development of the different regions, rather than any peculiarity of the demand for tools made by Greenwood and Batley.

The high level of foreign demand for the machine tools of Greenwood and Batley is of some intrinsic interest; for a closer examination of the demand in which the firm was operating, however, it is necessary to identify the industries to which their 653 customers belonged. In most cases, the order books and time ledgers give no indication of the industry in which the machine tool whose production they describe is to be used. In some cases the name of the customer gives some indication, in others the customer is so well known that identification is easy; the Electrical Power Storage Co. Ltd., the Imperial Turkish Armoury, or the Great Indian Peninsular Railway Co., are identifiable by the first method, Waterlow and Sons Ltd., Kynoch and Co.

Year	Home Orders £	Export Orders £	Total £
1856	3,433		3,433
57	1,279	1,686	2,965
58	2,499	1,527	4,026
59	14,937	1,389	16,326
1860	10,109	[illegible]	10,205
61	12,011	1,588	13,599
62	2,277	1,[illegible]96	4,[illegible]3
63	30,203	1,[illegible]10	31,[illegible]13
64	1,[illegible]81	2,522	4,[illegible]03
65	625		[illegible]25
66	5,841	2,146	7,987
67	3,054	13,664	16,718
68	1,046	11,323	12,369
69	5,839	10,[illegible]91	16,730
1870	14,817	8,754	23,571
71	13,178	38,722	51,900
72	23,931	3,522	27,453
73	3,377	9,203	12,580
74	11,[illegible]79	7,322	1[illegible],401
75	11,851	7,295	19,146
76	[illegible],[illegible]43	970	6,[illegible]13
77	[illegible],[illegible]1	3,111	[illegible],[illegible]92
78	[illegible],[illegible]5	4,765	11,[illegible]19
79	2,170	3,495	5,[illegible]65
1880	4,[illegible]94	6,034	10,[illegible]28
81	[illegible],674	[illegible],173	11,[illegible]52
82	13,951	7,681	21,[illegible]32
83	11,646	4,823	19,469
84	13,[illegible]22	7,753	21,275
85	45,199	1,329	46,528
86	39,772	11,[illegible]62	51,034
87	11,710	7,[illegible]80	21,790
88	2[illegible],[illegible]66	19,[illegible]60	42,926
89	20,716	24,[illegible]49	45,595
1890	7,[illegible]20	[illegible],62[illegible]	16,442
91	[illegible],[illegible]15	[illegible],168	39,[illegible]13
92	[illegible],72[illegible]	[illegible],7[illegible]	14,[illegible]96
93	[illegible],777	[illegible],63[illegible]	10,415
94	9,070	10,[illegible]27	19,597
95	4,733	15,725	20,508
96	17,257	13,76[illegible]	3[illegible],025
97	12,925	[illegible],194	18,[illegible]19
98	17,461	19,[illegible]20	[illegible]7,281
99	19,868	6,[illegible]44[illegible]	[illegible],7[illegible]3
1900	21,520	732	22,252

TABLE 5, 5. Home and foreign orders for machine tools from Greenwood and Batley Ltd, 1856 to 1900.

Table 5, 5, continued :

Note : These figures relate only to orders for which both price and cost are given.
Figures are in current prices.

Year	Area 1	2	3	4	5	6	7	8	9
1856		1	13	2		20			3
57	2	11	14	1		6			10
58	2	2	5			15			3
59	27	1	12			67			1
1860	39	8	22	2	2	20			2
61	4	1	23	38	1	33			1
62	12	1	6	8		11			
63		70	15	2	1	1	1		1
64	1	1	40	6		3			1
65		3	14	3		1			1
66	3	3	2			23			3
67		1	5	8		7			
68			9	1	1	7			
69	1		8	8	1	15			
1870	2	4	15	18		49			
71	1	1	18	29		27			1
72	1	8	23	70	2	20			
73		5	24	13		3			2
74	1	3	28	36		32			
75	5	2	11	13		47			
76		5	5	7		29			
77		4	5	18		16			3
78		1	11	5		27			
79		2	5			9		1	
1880	7		4	3		13			1
81	1	14	2	4		23			2
82	9	15	12	6		59			5
83	15	17	23	3	5	32			4
84	10	13	12	4		22	1		7
85	42	3	47	3	1	36			1
86	23	5	27	6	1	89	1		
87	14	6	25	3	1	54	2	1	2
88	8	6	21	17		60			2
89	4	12	60	9		44	1		
1890	5	3	22	11	1	20			5
91		5	25	10	2	9	3		1
92	2	3	11	6		14		1	1
93	1	2	17	5		17	2		
94		2	9	5		20	4		2
95	4	2	12	6	7	11			
96	10	5	41	25	3	54			1
97	4	5	19	15	2	21			1
98	5	3	17	7		14			
99	10	1	30	7		51	3		
1900	8	3	30	7	3	46	6	6	2

TABLE 5, 6, Greenwood and Batley. Sales to home customers 1856-1900, broken down by location of customer.

Table 5, 6, continued :

Key to Areas : 1. Northern England
2. North-West England
3. North-East England
4. Midlands Industrial
5. Midlands Agricultural
6. South-East England
7. South-West and South England
8. South Wales
9. Scotland and Ireland

. . The figures for Leeds, in group 3, include 'orders' from Greenwood and Batley itself.

or Friedrich Krupp of Essen by the second. To supplement these methods, the Directories of Merchants and Manufacturers, used in the chapter above on the structure of the engineering industry during the period, were searched for the names of the customers of Greenwood and Batley. By these means it was possible to identify the majority of the 653 customers, although 112 British and 139 foreign customers could not be positively identified. Fortunately, the more important customers were easier to identify; well over 85% by value of the machine tools sold could be allotted to particular industries. One difficulty was that in some cases machine tools were sold to the multi-product engineering firms described above, such as Whitworth or Armstrong or Krupp, and of course there is no indication of the exact product on which they were to be employed. In these cases, one of three courses could have been adopted. The machine tools could have been allotted to only one of the product or industry groups in which the customer was known to be involved they could have been allotted to all these groups, either in total or divided up in some arbitrary way, or they could have been relegated to the 'other identified' category. None of these alternatives is entirely satisfactory. The first, and the method of arbitrary division, involves a judgement on the composition of production inside a firm like Whitworth, for which no evidence is available. The method of allocation to all groups produces an element of double counting, and is unsatisfactory particularly if the products of the customer changed markedly over time. The third alternative, relegation to 'other identified', would aggregate the £10,000 worth of machine tools bought by Armstrong, Mitchell in 1835 with the one lathe bought by an amateur turner, F. Boynton, Esq.,

of Bromley Hill, Croydon, in 1878, thus producing a group of little homogeneity. After experimentation with different methods, it was decided to adopt that of allotting the total volume of sales to a customer like Armstrong or Whitworth to all the industries in which that firm is known to have been involved. The element of double counting is quite large; total sales over the period amounted to £892,318, while the sum of the industry groups listed in table 5,7 is £1,014,305. On the other hand, since the allocation of sales to groups is known, and presented in table 5, 7, the effects of this double counting can be discounted in the non-numerical considerations of the experience of the different industries. Since broader categories, which are less likely to be subject to double-counting, are in general used in the numerical investigation of the differences between groups of customers which are described below, and since the element of double counting is important only within a few related groups (such as steam-engine manufacture, hydraulics, pumps and cranes and other home engineering industries) this method seems to have less dangers and to provide more information than the other methods of presentation which were considered.

Table 5, 7, shows the results of dividing the sales of machine tools by Greenwood and Batley in terms of the industry of the customer, by the method described. Graphs of the year by year sales to each of the customer groups are given as graphs 5, 1 to 25.

It is clear from those graphs that the pattern of sales over time varied very greatly from one customer group to another, and that analysis of the sales made by Greenwood and Batley needs therefore to be accompanied by description of

Industry	No. of customers in group	Total sales to group £	No. of years in which sales made	Year First	La
1. British Government	23	169,814	41	1856	190
2. Colonial Governments	13	60,701	40	1859	189
3. Foreign Governments	42	223,514	39	1859	189
4. Armaments : Home	43	166,539	42	1856	190
5. Armaments : Foreign and Colonial	19	35,485	23	1867	190
6. Machine Tools : Home	33	21,239	34	1857	190
7. Hand Tools : Home	30	14,320	30	1860	190
8. General Engineering : Home	38	39,929	35	1857	190
9. Textile Machinery : Home	29	10,192	28	1856	189
10. Electrical Machinery : Home	25	11,204	16	1859	*189
11. Sewing Machines : Home	11	3,229	16	1867	189
12. Agricultural Machinery : Home	35	3,688	20	1860	190
13. Cycles : Home	20	4,455	6	1890	189
14. Steam Engines : Home	48	49,685	41	1857	190
15. Railways : Home	13	15,953	26	1858	190
16. Railways : Foreign and Colonial	19	10,958	18	1859	189
17. Iron and Steel Trades : Home	15	15,952	16	1857	190
18. Shipbuilding : Home	6	1,293	6	1859	189
19. Hydraulics, Pumps and Cranes : Home	24	51,193	38	1857	190
20. Printing and Paper	8	620	7	1857	189
21. Locks	2	484	5	1858	187
22. Miscellaneous identified	25	3,489	15	1878	190
23. Unidentified : Home	112	31,951	42	1856	190
24. Unidentified : Foreign	139	78,478	41	1857	189

TABLE 5. 7. Greenwood and Batley. Distribution of customers and sales by industrial group of customer, 1856-1900.

* This unlikely figure is the result of difficulties in defining exactly the product group to which a particular firm belonged. The next sale to an electrical equipment manufacturer was in 1872, and the major sales to this group occurred after 1880.
Prices are current prices.

GRAPHS 5, 1 to 25: Explanatory notes.

1. The vertical scale represents years from 1840. Thus 16 represents 1840 + 16, or 1856. 60 therefore represents 1900. This arrangement was dictated by computing requirements.

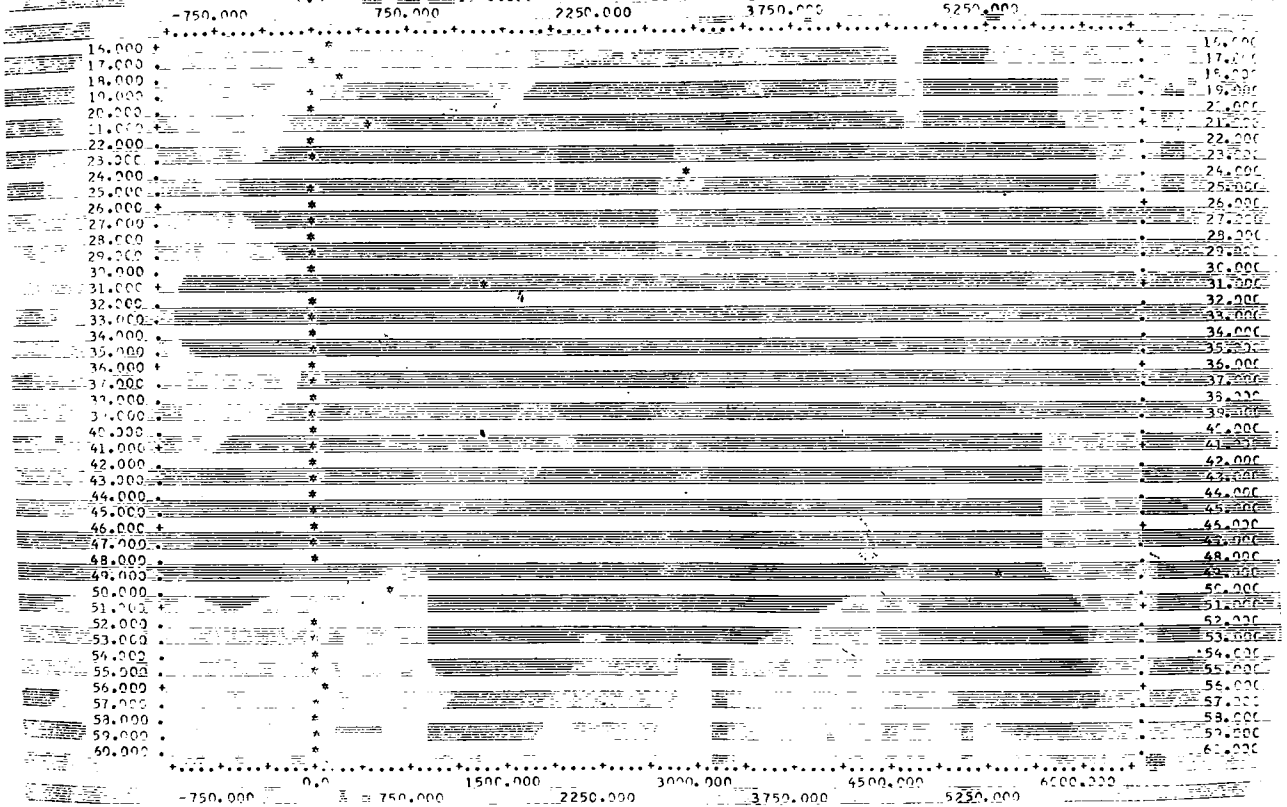
2. The horizontal scale gives value of orders in £s, at current prices.

3. The intervals on the horizontal scale vary as between one graph and another, to accomodat the wide variations in total value of sales as between different groups of customers. A figure somewhat above the maximum value of orders attained between 1856 and 1860 is used to determine the right-hand value on each horizontal scale, and the scale is then adjust to provide equal intervals between that right-hand, maximum, value and zero.

4. The graphs were plotted using the Biomedical computing routines developed at the University of California, Los Angeles, details of which can be found in BMD: Biomedical Computer Programs, ed. W.J. Dixon (University of California Press, Berkeley and Los Angeles, 1967) and subsequent revisions.

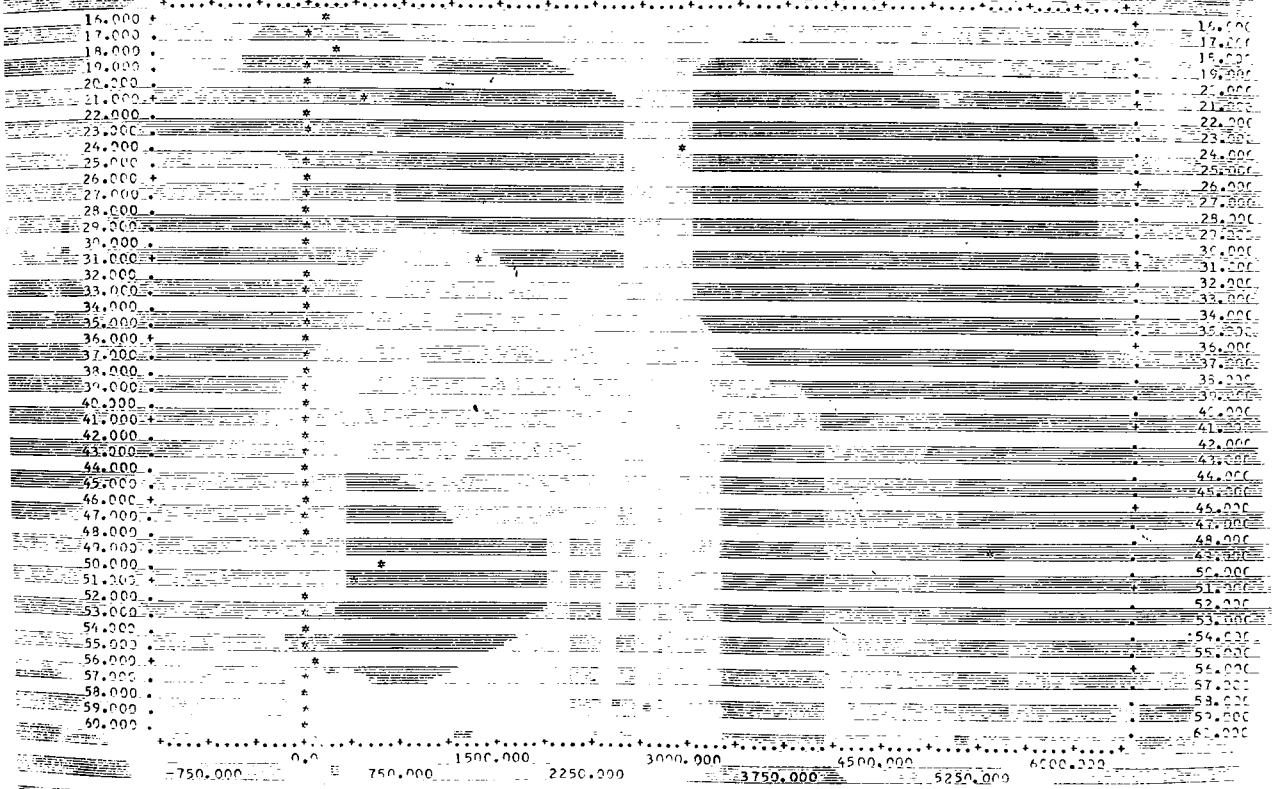
GRAPH 5, 1

YEARLY VALUE OF ORDERS FROM CUSTOMER GROUPS. 1. GREENWOOD AND BATLEY. Stock and Utensils.



GRAPH 5, 1

YEARLY VALUE OF ORDERS FROM CUSTOMER GROUPS. 1. GREENWOOD AND BATLEY. Stock and Utensils.



NB. Ended since in most cases 'Pace' was at

...PLOT - INCLUDING HISTOGRAM ... REVISED JANUARY 27, 1969
...COMPUTER FACILITY, ... GRAPH 5,2.

PLOT OF VARIABLE 1 (VERTICAL AXIS) VERSUS VARIABLE(S) 2 (SYMBOL=*),

YEARLY VALUE OF ORDERS FROM CUSTOMER G CODE=2 BRITISH GOVERNMENT

3000.000 6000.000 9000.000 12000.000 15000.000 18000.000 21000.000 24000.000 27000.000

16.000 17.000 18.000 19.000 20.000 21.000 22.000 23.000 24.000 25.000 26.000 27.000 28.000 29.000 30.000 31.000 32.000 33.000 34.000 35.000 36.000 37.000 38.000 39.000 40.000 41.000 42.000 43.000 44.000 45.000 46.000 47.000 48.000 49.000 50.000 51.000 52.000 53.000 54.000 55.000 56.000 57.000 58.000 59.000 60.000

YEARLY VALUE OF ORDERS FROM CUSTOMER GROUPS.03 COLONIAL GOVERNMENTS

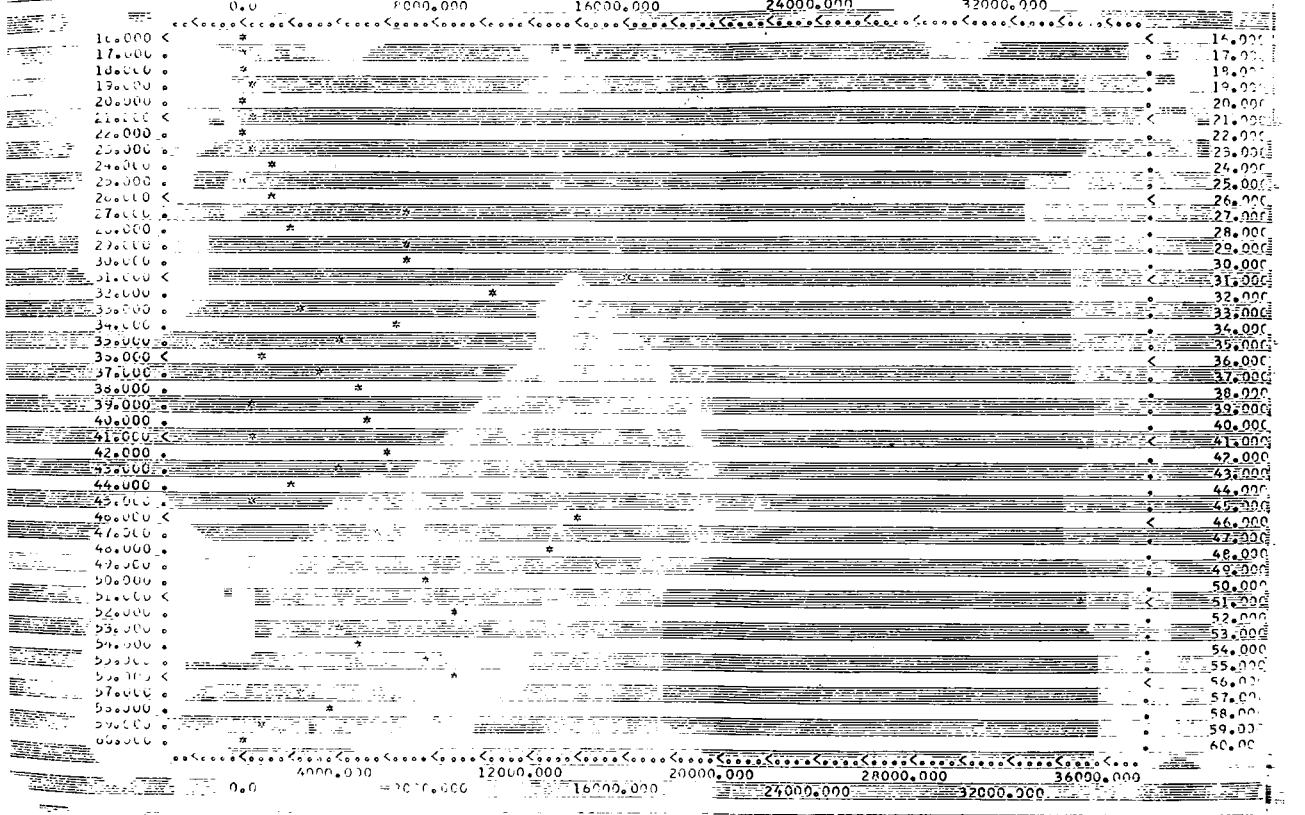
-1500.000 0.0 1500.000 3000.000 4500.000 6000.000 7500.000 9000.000 10500.000 12000.000

16.000 17.000 18.000 19.000 20.000 21.000 22.000 23.000 24.000 25.000 26.000 27.000 28.000 29.000 30.000 31.000 32.000 33.000 34.000 35.000 36.000 37.000 38.000 39.000 40.000 41.000 42.000 43.000 44.000 45.000 46.000 47.000 48.000 49.000 50.000 51.000 52.000 53.000 54.000 55.000 56.000 57.000 58.000 59.000 60.000

-1500.000 0.0 1500.000 3000.000 4500.000 6000.000 7500.000 9000.000 10500.000 12000.000

YEARLY VALUE OF ORDERS FROM CUSTOMER GROUPS.04 FOREIGN GOVERNMENTS

PLOT OF VARIABLE 1 (VERTICAL AXIS) VERSUS VARIABLE(S) 2 (SYMBOL=*),



...AL PLOT - INCLUDING HISTOGRAM VERSION OF APRIL 1, 1966
...TE SCIENCES COMPUTING FACILITY, UCLA GRAPH 5,5

YEARLY VALUE OF ORDERS FROM CUSTOMER GROUPS.05 ARMAMENTS HOME

0.0 8000.000 16000.000 24000.000 32000.000

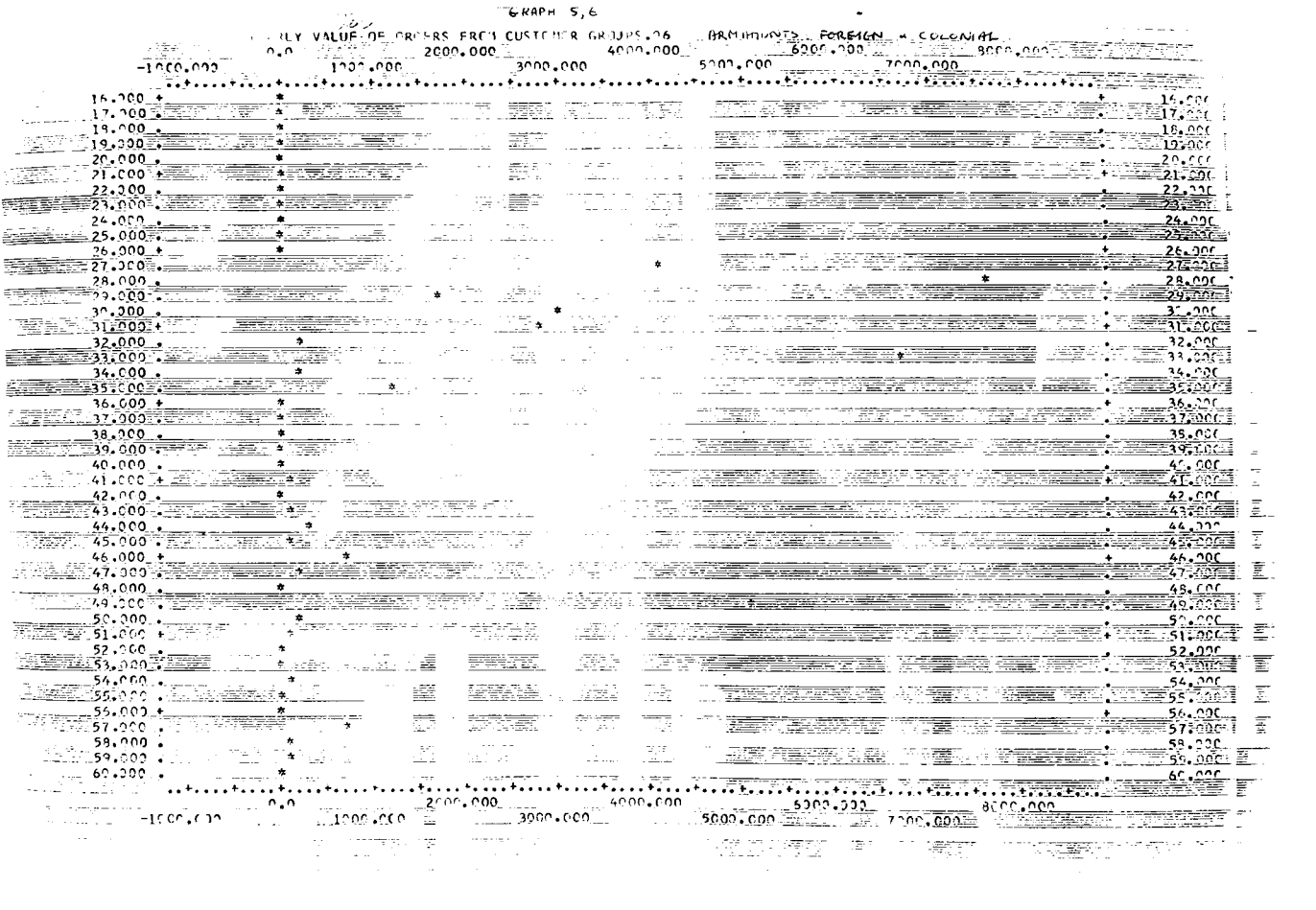
-4000.000 4000.000 12000.000 20000.000 28000.000

16.000 +
17.000 .
18.000 .
19.000 .
20.000 .
21.000 +
22.000 .
23.000 .
24.000 .
25.000 .
26.000 +
27.000 .
28.000 .
29.000 .
30.000 .
31.000 +
32.000 .
33.000 .
34.000 .
35.000 .
36.000 +
37.000 .
38.000 .
39.000 .
40.000 .
41.000 +
42.000 .
43.000 .
44.000 .
45.000 .
46.000 +
47.000 .
48.000 .
49.000 .
50.000 .
51.000 +
52.000 .
53.000 .
54.000 .
55.000 .
56.000 +
57.000 .
58.000 .
59.000 .
60.000 .

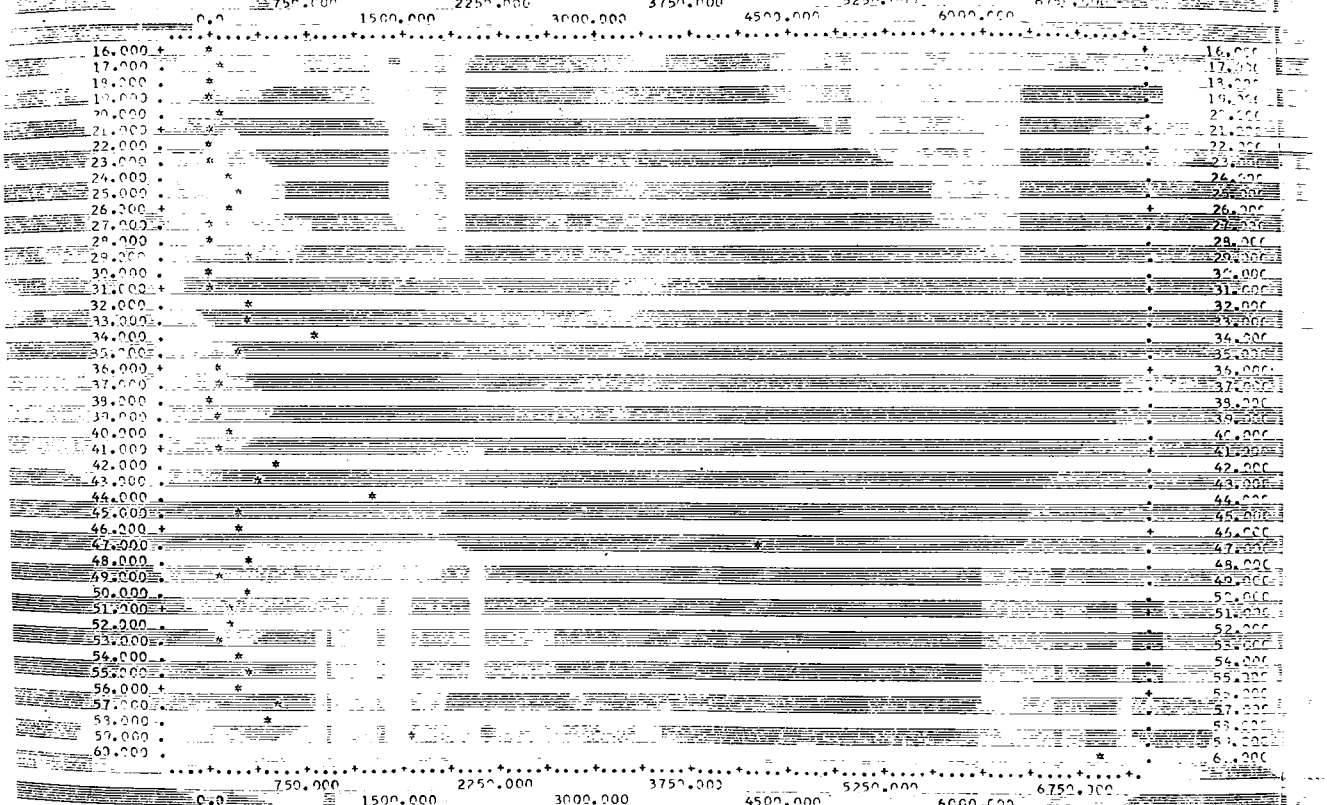
0.0 8000.000 16000.000 24000.000 32000.000

-4000.000 4000.000 12000.000 20000.000 28000.000

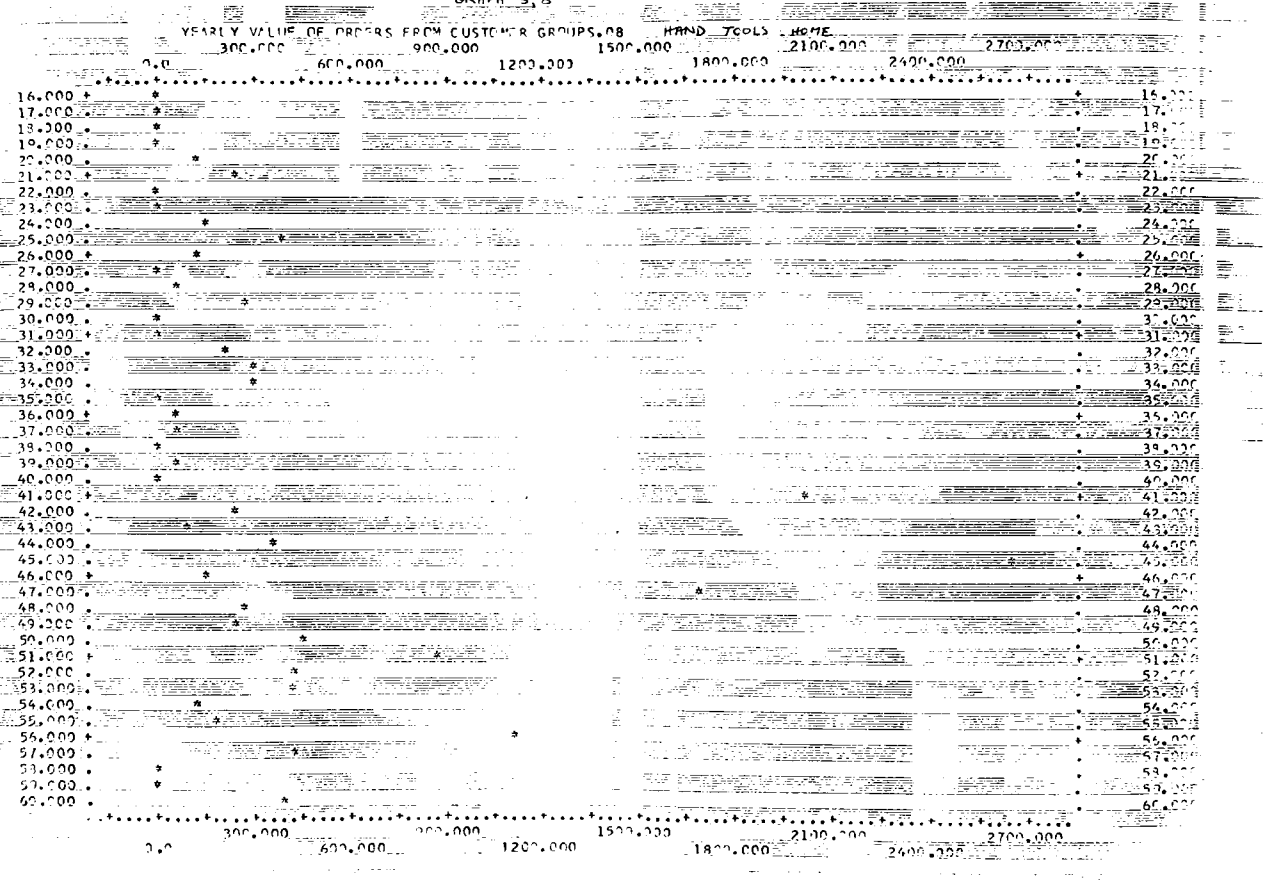
GRAPH 5,6


ILY VALUE OF ORDERS FROM CUSTOMER GROUPS 26 ARMAMENTS, FOREIGN & COLONIAL
0.0
2000.000
4000.000
6000.000
8000.000
-1000.000
1000.000
3000.000
5000.000
7000.000
16.000
17.000
18.000
19.000
20.000
21.000
22.000
23.000
24.000
25.000
26.000
27.000
28.000
29.000
30.000
31.000
32.000
33.000
34.000
35.000
36.000
37.000
38.000
39.000
40.000
41.000
42.000
43.000
44.000
45.000
46.000
47.000
48.000
49.000
50.000
51.000
52.000
53.000
54.000
55.000
56.000
57.000
58.000
59.000
60.000

GRAPH 57.1

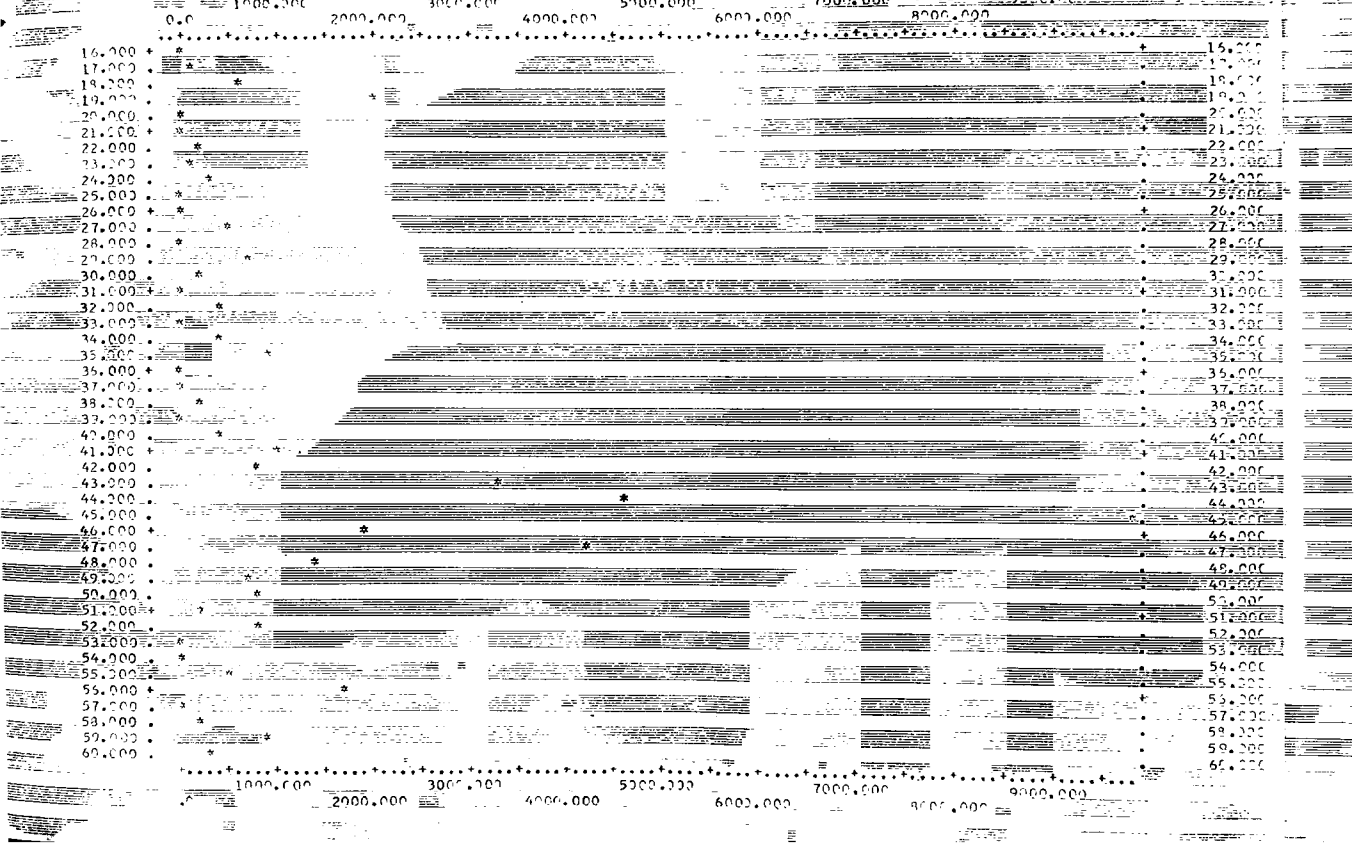

YEARLY VALUE OF ORDERS FROM CUSTOMER GROUPS.07 MACHINE TOOLS, HOME
750.000
2250.000
3750.000
5250.000
6750.000
0.0
1500.000
3000.000
4500.000
6000.000
16.000
17.000
18.000
19.000
20.000
21.000
22.000
23.000
24.000
25.000
26.000
27.000
28.000
29.000
30.000
31.000
32.000
33.000
34.000
35.000
36.000
37.000
39.000
39.000
40.000
41.000
42.000
43.000
44.000
45.000
46.000
47.000
48.000
49.000
50.000
51.000
52.000
53.000
54.000
55.000
56.000
57.000
58.000
59.000
60.000

GRAPH 5.8


YEARLY VALUE OF ORDERS FROM CUSTOMER GROUPS.08 HAND TOOLS HOME
300,000
600,000
900,000
1200,000
1500,000
1800,000
2100,000
2400,000
2700,000
0.0
16.000
17.000
18.000
19.000
20.000
21.000
22.000
23.000
24.000
25.000
26.000
27.000
28.000
29.000
30.000
31.000
32.000
33.000
34.000
35.000
36.000
37.000
38.000
39.000
40.000
41.000
42.000
43.000
44.000
45.000
46.000
47.000
48.000
49.000
50.000
51.000
52.000
53.000
54.000
55.000
56.000
57.000
58.000
59.000
60.000

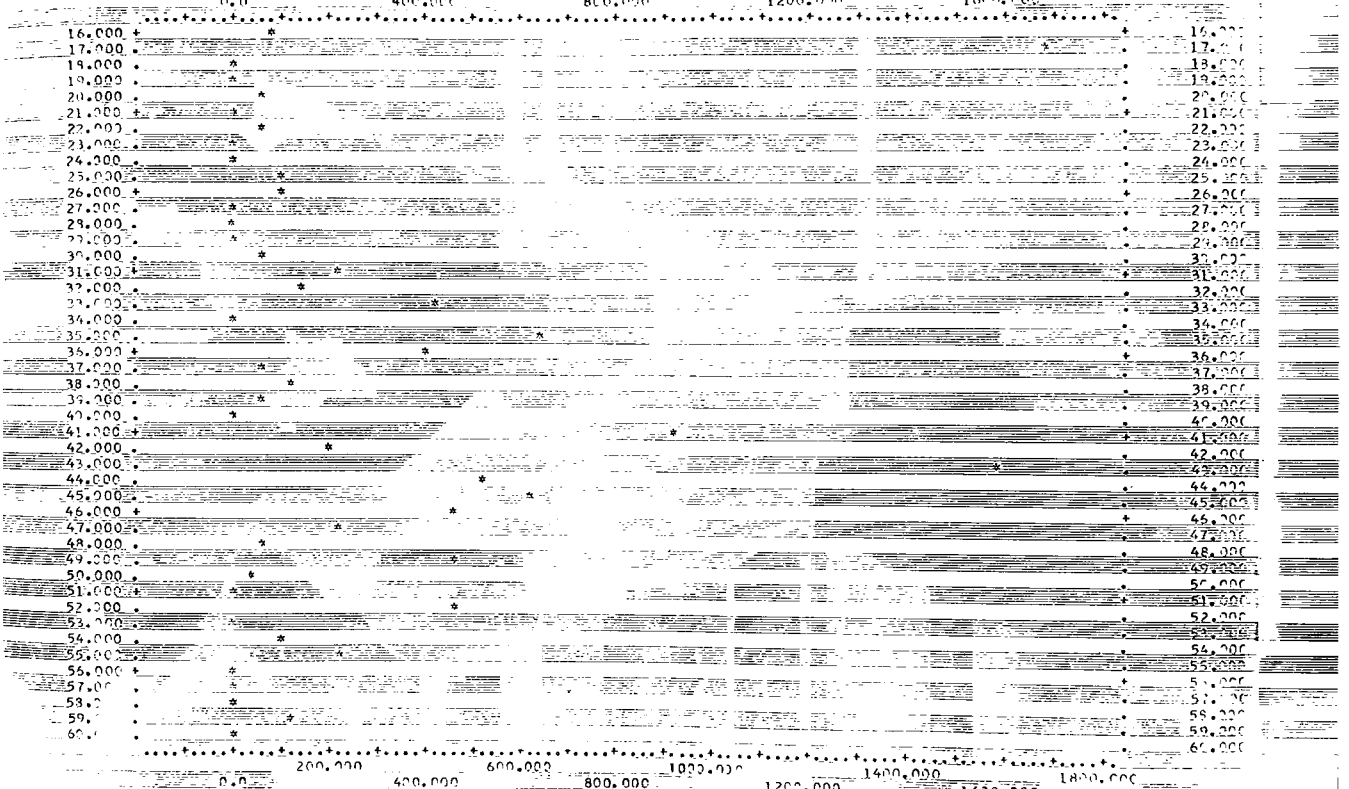
GRAPH 5,9

YEARLY VALUE OF ORDERS FROM CUSTOMER GROUPS.99 GENERAL ENGINEERING - HOME



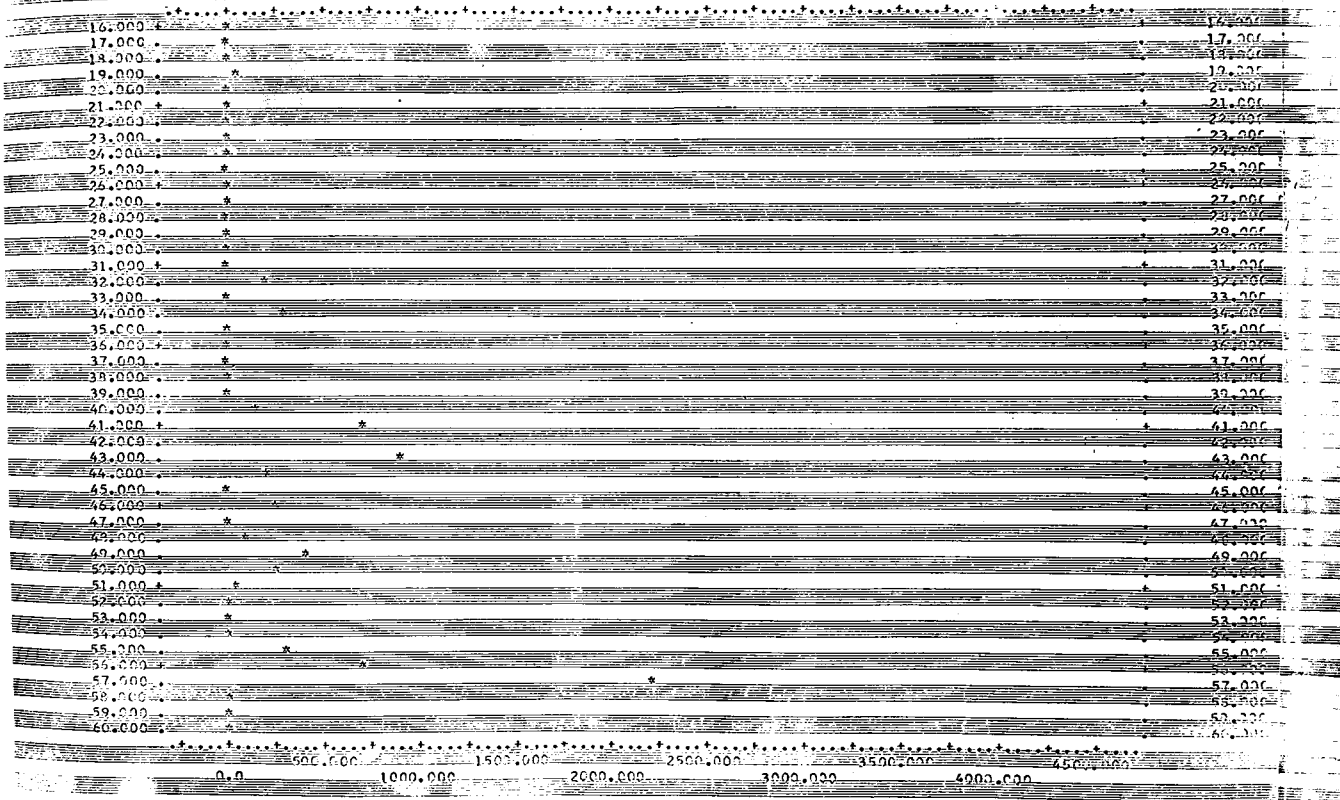
GRAPH 5,10

YEARLY VALUE OF ORDERS FROM CUSTOMER GROUPS.12 TEXTILE, MACHINERY, HOME



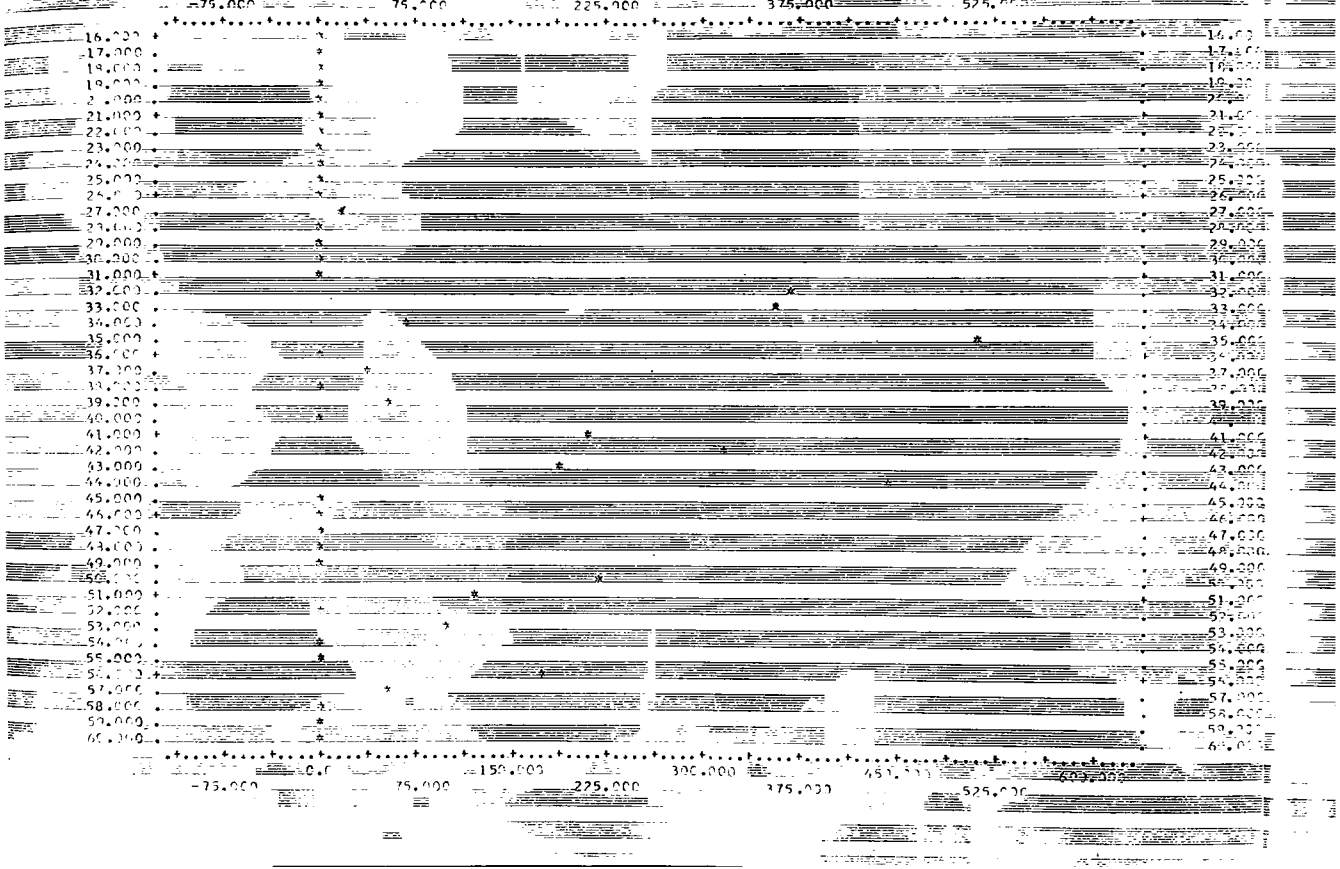
GRAPH 5,11

YEARLY VALUE OF ORDERS FROM CUSTOMER GROUPS.11 ELECTRICAL MACHINERY HOME

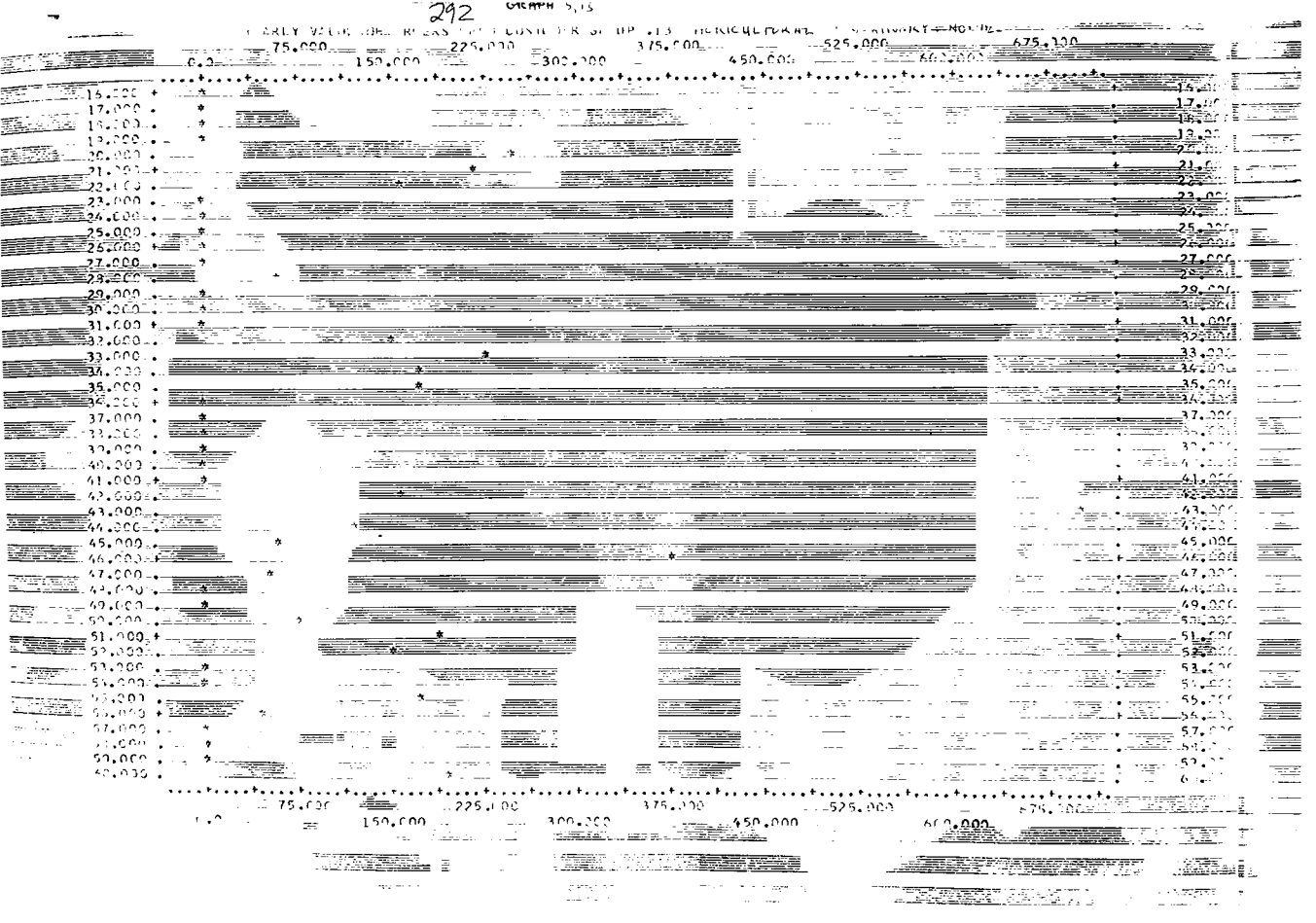


GRAPH 5,12

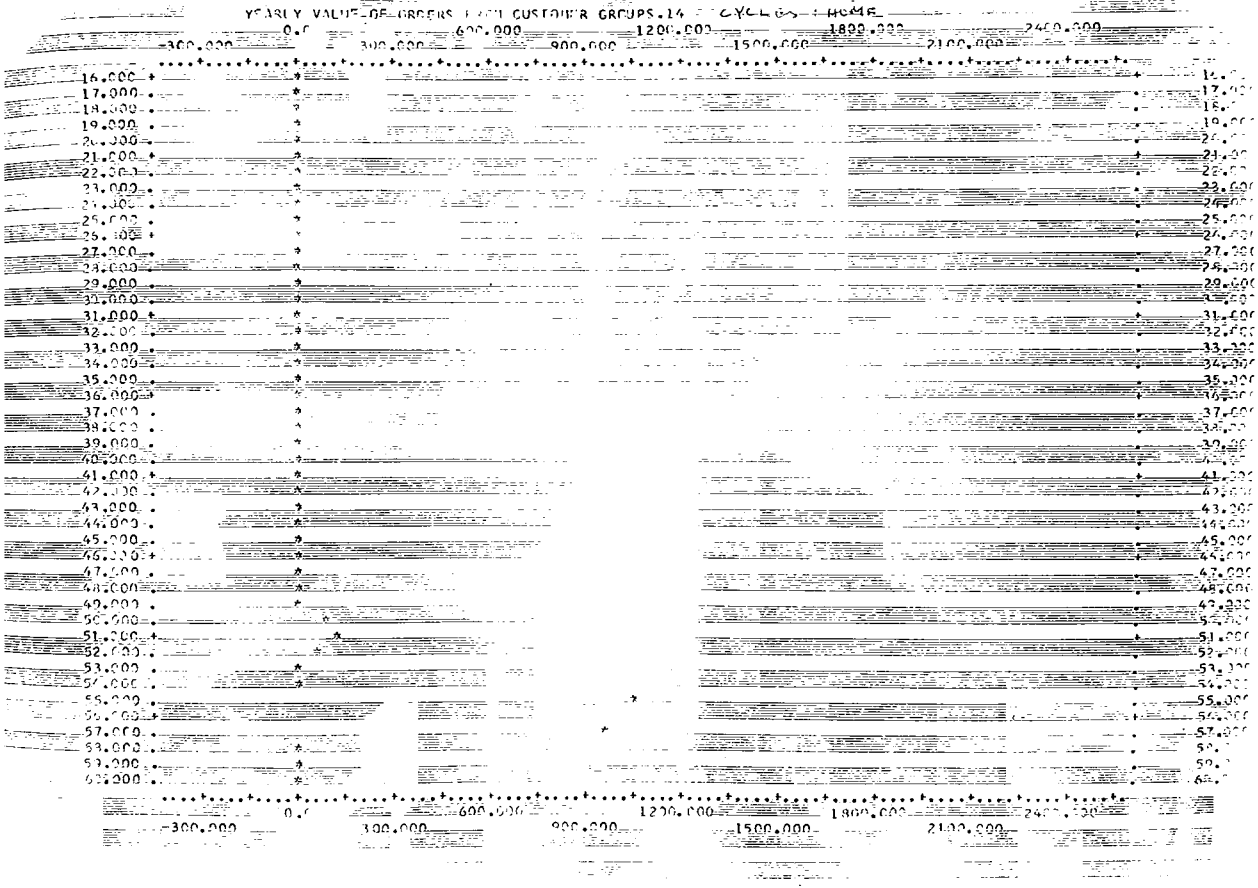
YEARLY VALUE OF ORDERS FROM CUSTOMER GROUPS 12 SEWING MACHINES, MOTOR



GRAPH 5.15



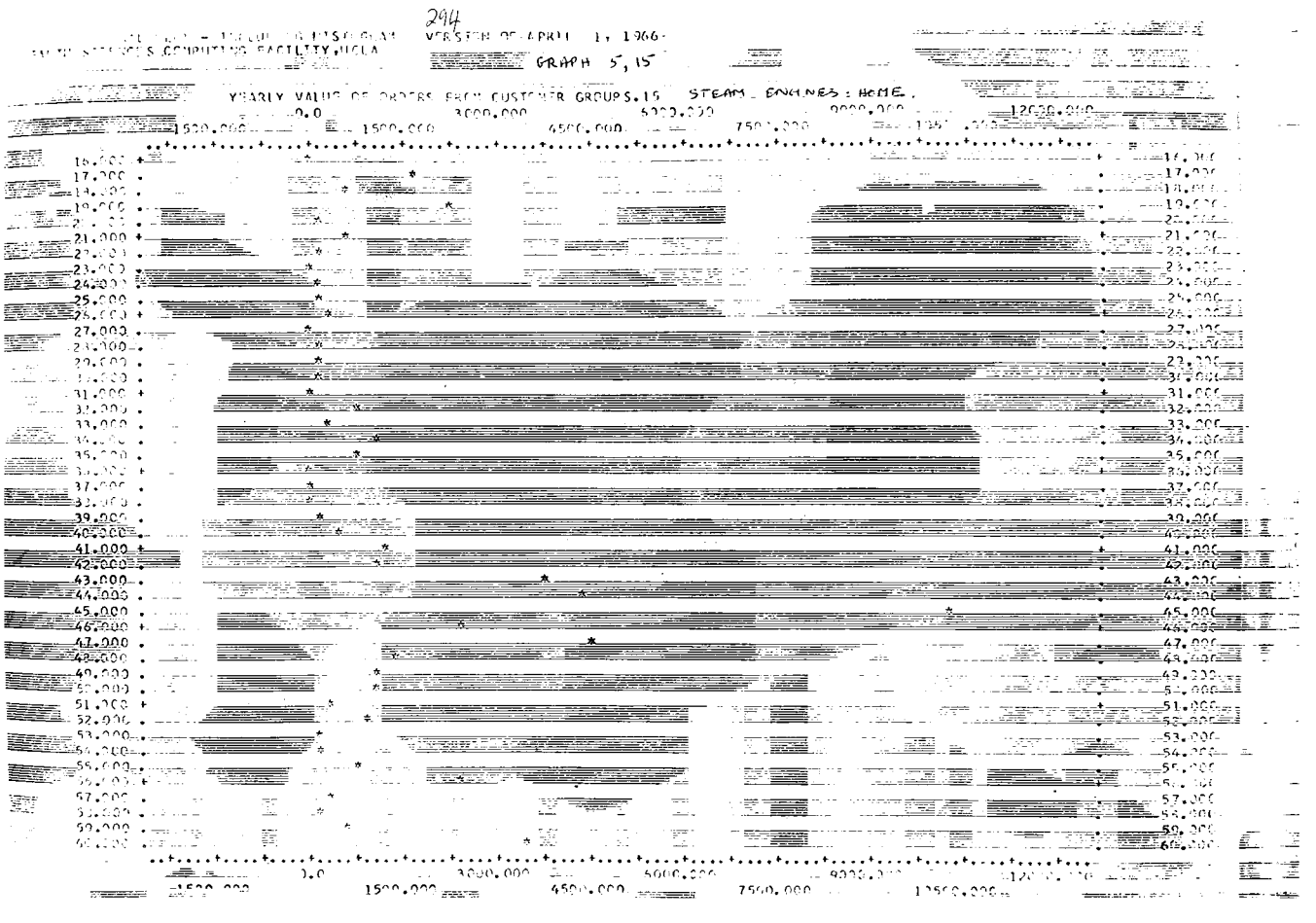
GRAPH 5.14


YEARLY VALUE OF ORDERS FOR CUSTOMER GROUPS 14 - CYCLES - HOME
0.0
600.000
1200.000
1800.000
2400.000
-300.000
300.000
900.000
1500.000
2100.000

VERSION OF APRIL 1, 1966.

GRAPH 5, 15

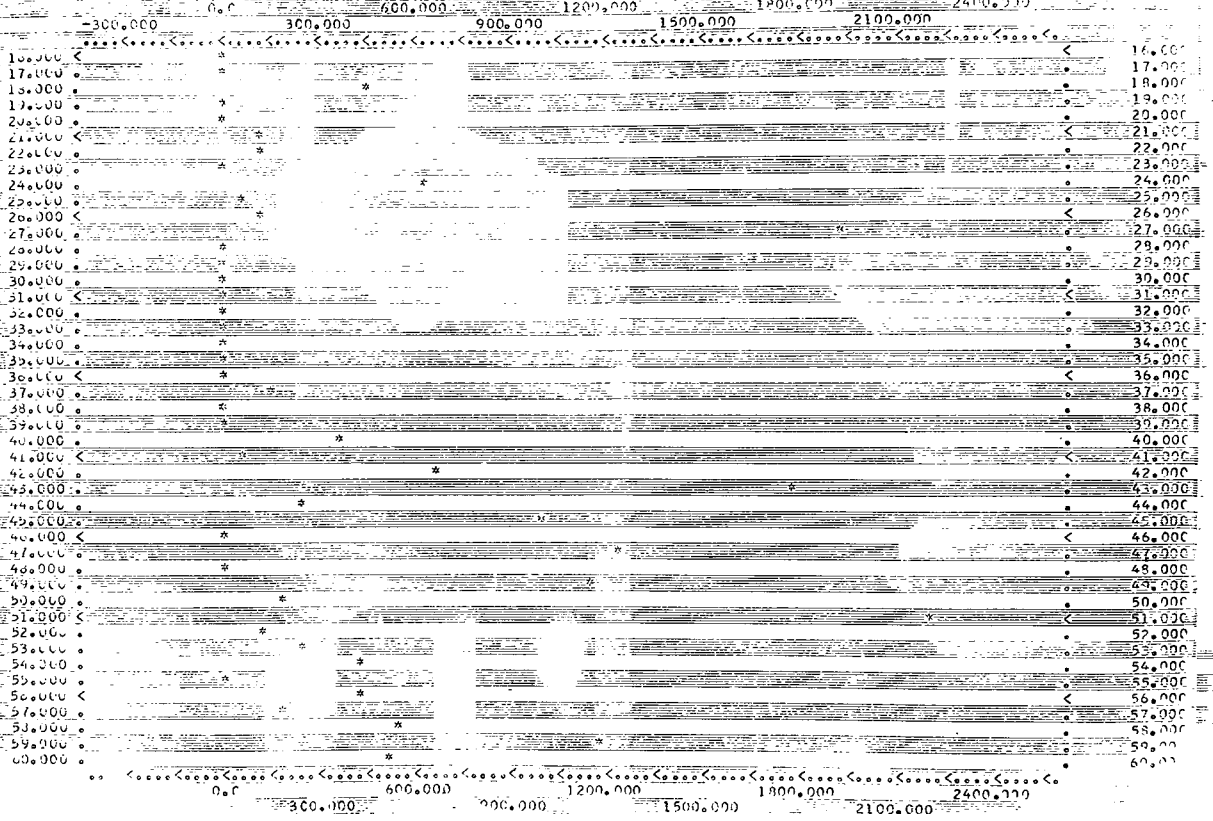
YEARLY VALUE OF ORDERS FROM CUSTOMER GROUPS.15 STEAM ENGINES : HOME.



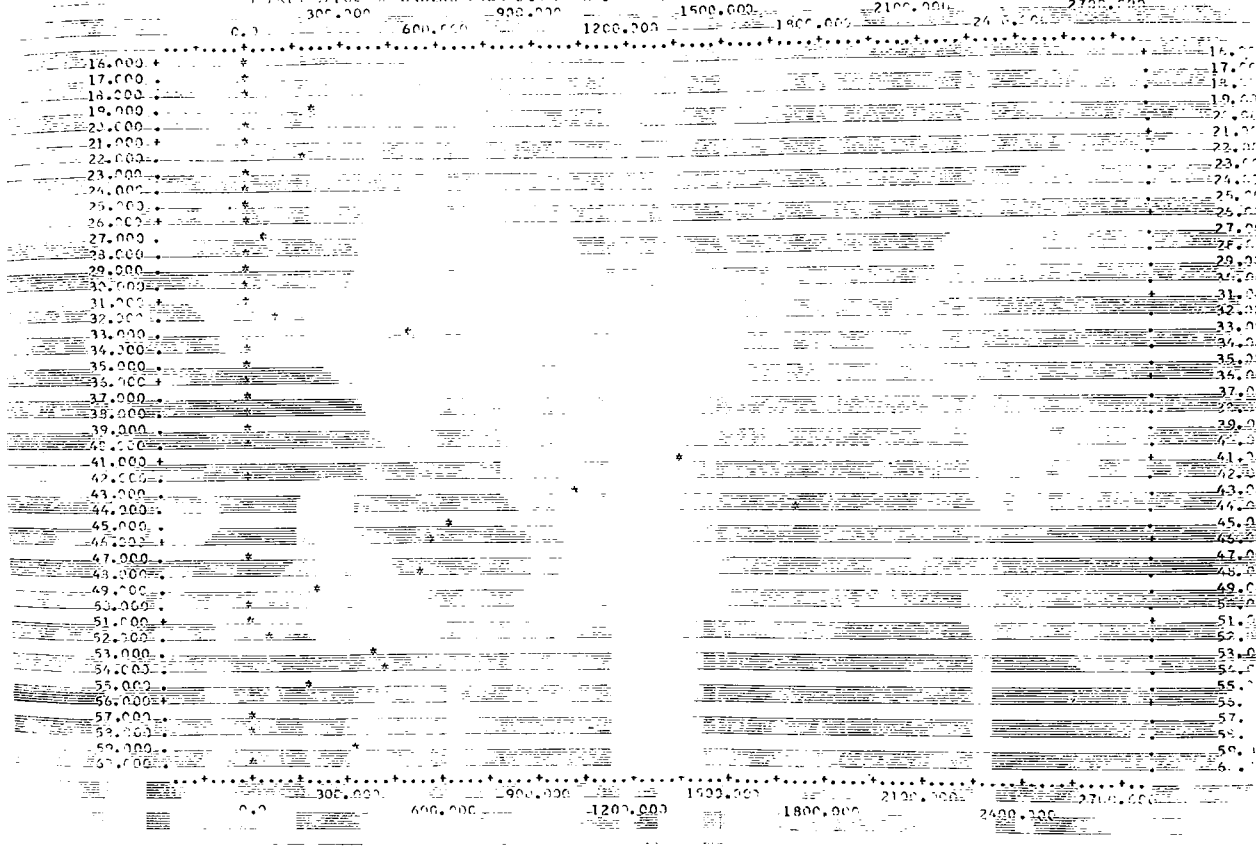
SYSTEM PLOT - INCLUDING HISTOGRAM - REVISED JANUARY 27, 1969.
HEALTH SCIENCES COMPUTING FACILITY, UCLA GRAPH 5,16

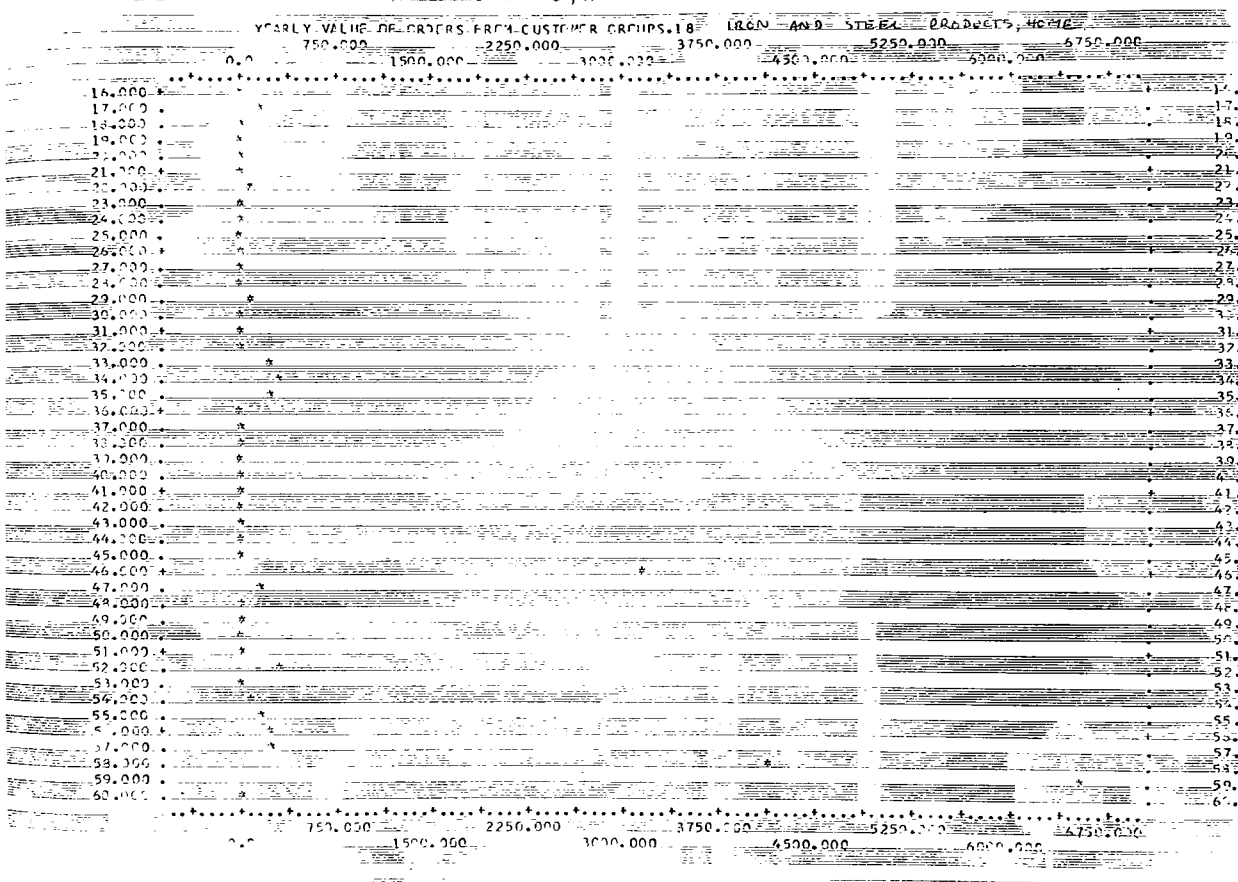
YEARLY VALUE OF ORDERS FROM CUSTOMER GROUPS.1% RAILWAYS HOME

PLOT OF VARIABLE 1 (VERTICAL AXIS) VERSUS VARIABLE(S) 2 (SYMBOL=).



GRAPH 5, 17

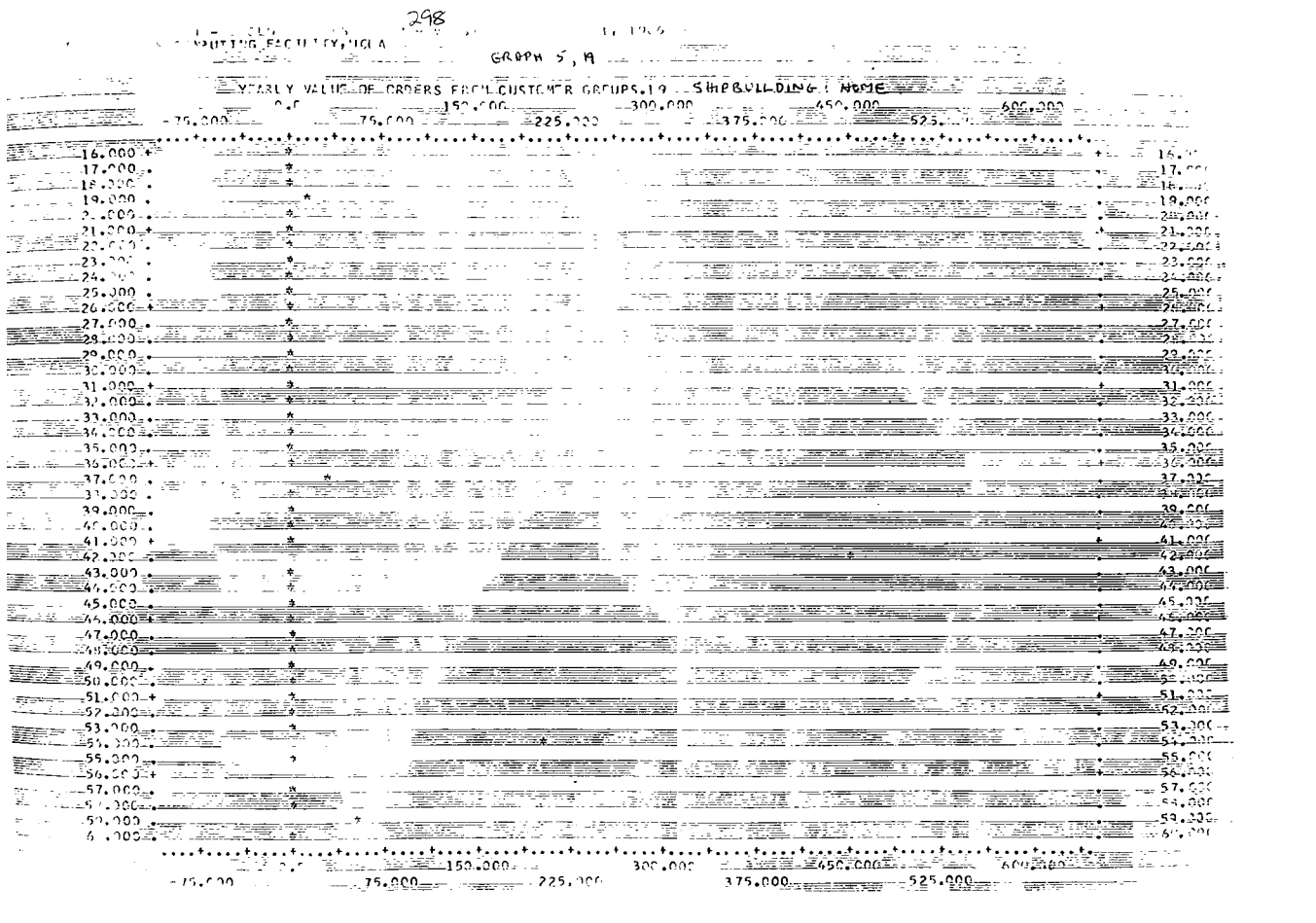

YEARLY VALUE OF ORDERS FROM CUSTOMER GROUPS.17 RAILWAYS FOREIGN & COLONIAL
300,000
600,000
900,000
1200,000
1500,000
1800,000
2100,000
2400,000
2700,000
16,000
17,000
18,000
19,000
20,000
21,000
22,000
23,000
24,000
25,000
26,000
27,000
28,000
29,000
30,000
31,000
32,000
33,000
34,000
35,000
36,000
37,000
38,000
39,000
40,000
41,000
42,000
43,000
44,000
45,000
46,000
47,000
48,000
49,000
50,000
51,000
52,000
53,000
54,000
55,000
56,000
57,000
58,000
59,000
60,000


YEARLY VALUE OF ORDERS FROM CUSTOMER GROUPS.18 IRON AND STEEL PRODUCTS, HOME
750.000
2250.000
3750.000
5250.000
6750.000
0.0
1500.000
3000.000
4500.000
6000.000
16.000
17.000
18.000
19.000
20.000
21.000
22.000
23.000
24.000
25.000
26.000
27.000
28.000
29.000
30.000
31.000
32.000
33.000
34.000
35.000
36.000
37.000
38.000
39.000
40.000
41.000
42.000
43.000
44.000
45.000
46.000
47.000
48.000
49.000
50.000
51.000
52.000
53.000
54.000
55.000
56.000
57.000
58.000
59.000
60.000

COMPUTING FACILITY, UCLA

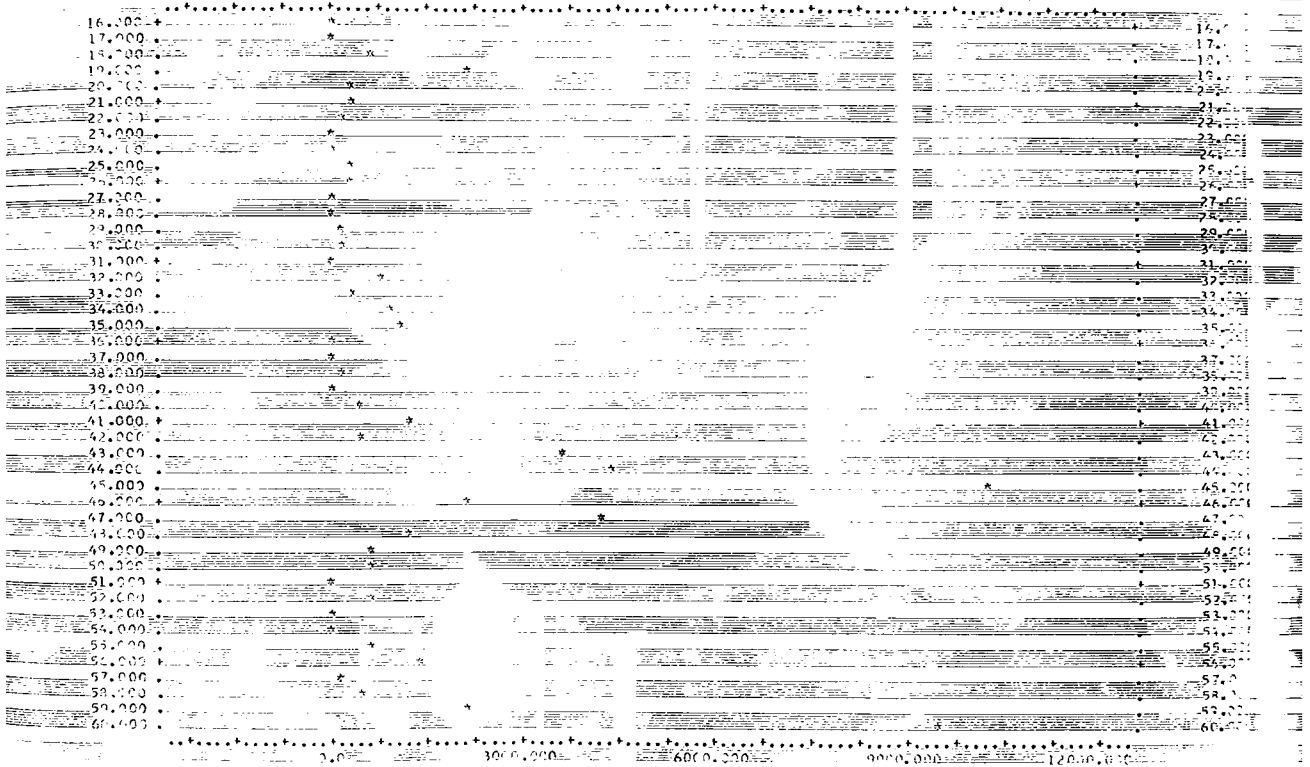
GRAPH 5, 19

YEARLY VALUE OF ORDERS FROM CUSTOMER GROUPS 19 - SHIPBUILDING INDUSTRY



GRAPH 5, 20

YEARLY VALUE OF ORDERS FROM CUSTOMER GROUPS 20 HYDRAULICS PUMPS & CRANES NEAR



#300 GRAPH 5.21

YEARLY VALUE OF ORDERS FROM CUSTOMER GROUPS.21 - PRINTING AND PAPER MACHINERY HOME

PLOT OF VARIABLE 1 (VERTICAL AXIS) VERSUS VARIABLE(S) 2 (SYMBOL=*),

-20.000 20.000 60.000 100.000 140.000 180.000

-5.000 40.000 80.000 120.000 160.000

16.000 17.000 18.000 19.000 20.000 21.000 22.000 23.000 24.000 25.000 26.000 27.000 28.000 29.000 30.000 31.000 32.000 33.000 34.000 35.000 36.000 37.000 38.000 39.000 40.000 41.000 42.000 43.000 44.000 45.000 46.000 47.000 48.000 49.000 50.000 51.000 52.000 53.000 54.000 55.000 56.000 57.000 58.000 59.000 60.000

-20.000 20.000 60.000 100.000 140.000 180.000

-5.000 40.000 80.000 120.000 160.000

GRAPH 5,22

YEARLY VALUE OF ORDERS FROM CUSTOMER GROUPS,22 - LOCKS HOME

PLOT OF VARIABLE 1 (VERTICAL AXIS) VERSUS VARIABLE(S) 22(SYMBOL=*),

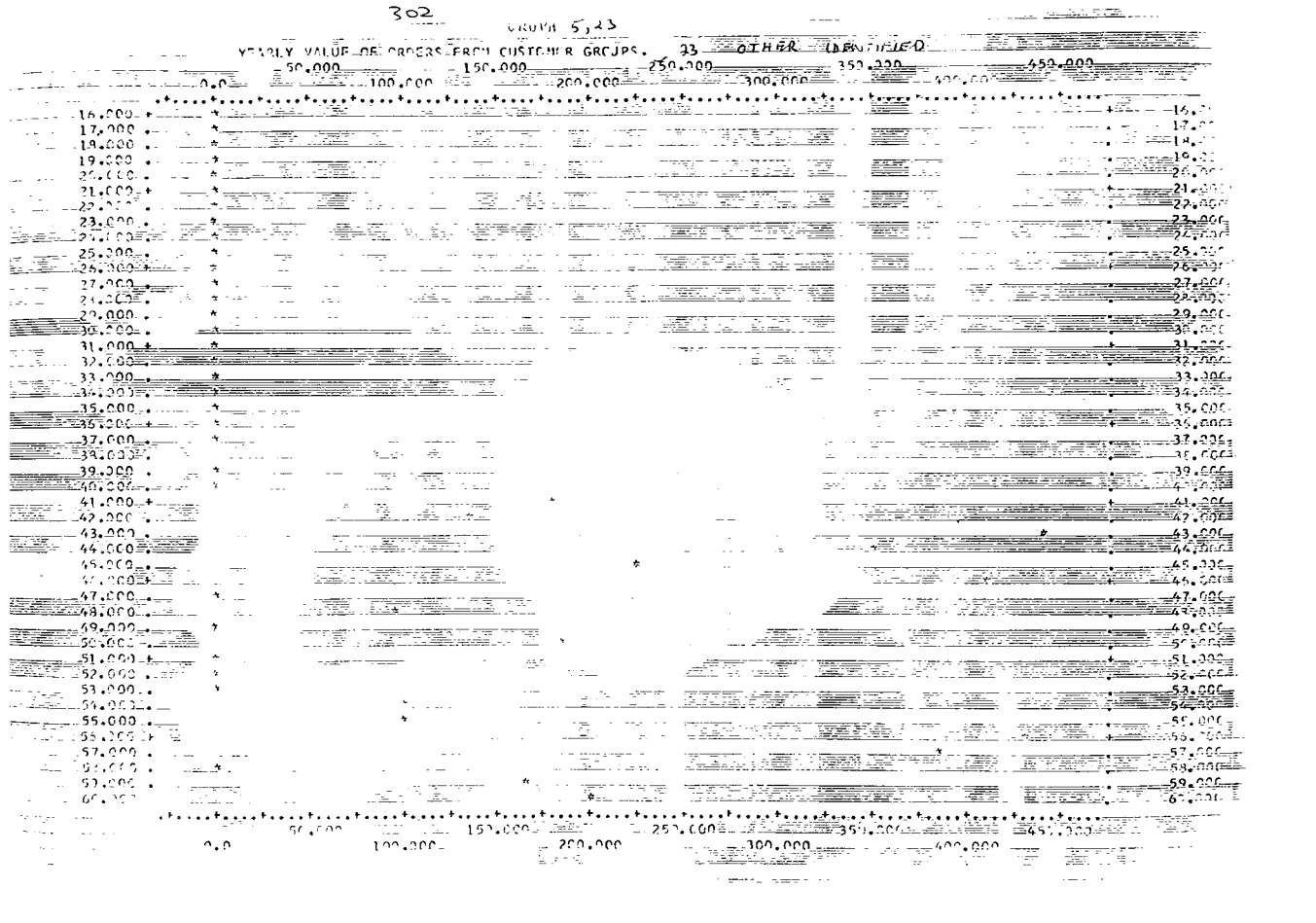
-30.000 0.000 30.000 60.000 90.000 120.000 150.000 180.000 210.000 240.000

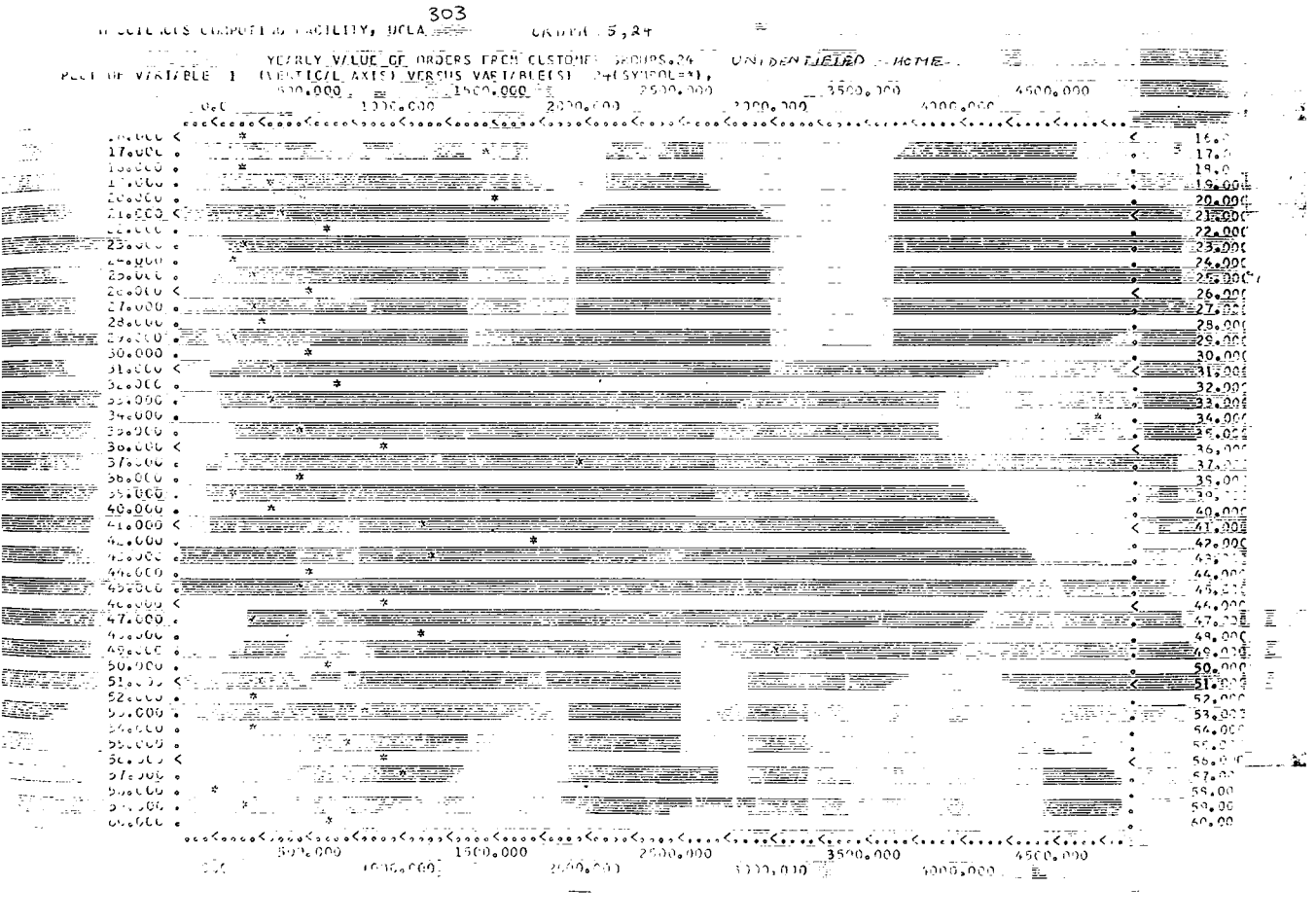
16.000 17.000 18.000 19.000 20.000 21.000 22.000 23.000 24.000 25.000 26.000 27.000 28.000 29.000 30.000 31.000 32.000 33.000 34.000 35.000 36.000 37.000 38.000 39.000 40.000 41.000 42.000 43.000 44.000 45.000 46.000 47.000 48.000 49.000 50.000 51.000 52.000 53.000 54.000 55.000 56.000 57.000 58.000 59.000 60.000

-0.000 60.000 120.000 180.000 240.000

GROUP 5,43

YEARLY VALUE OF ORDERS FROM CUSTOMER GROUPS. 33 OTHER (UNIDENTIFIED




YEARLY VALUE OF ORDERS FROM CUSTOMER GROUPS=24 UNIDENTIFIED - HOME-
PLOT OF VARIABLE 1 (VERTICAL AXIS) VERSUS VARIABLE(S) 2+(SYMBOL=*),
500.000
1000.000
1500.000
2000.000
2500.000
3000.000
3500.000
4000.000
4500.000
16.000
17.000
18.000
19.000
20.000
21.000
22.000
23.000
24.000
25.000
26.000
27.000
28.000
29.000
30.000
31.000
32.000
33.000
34.000
35.000
36.000
37.000
38.000
39.000
40.000
41.000
42.000
43.000
44.000
45.000
46.000
47.000
48.000
49.000
50.000
51.000
52.000
53.000
54.000
55.000
56.000
57.000
58.000
59.000
60.000

[illegible] - [illegible] - REVISED JANUARY 27, 1965
[illegible] COMPUTING CENTER, UCLA GRAPH 5, 25

YEARLY VALUE OF ORDERS FROM CUSTOMER GROUPS 25 UNIDENTIFIED FOREIGN AND COLONIAL

PLOT OF VARIABLE 1 (VERTICAL AXIS) VERSUS VARIABLE(S) 2 (SYMBOL=*).

3000.000 6000.000 9000.000 12000.000
-1500.000 1500.000 4500.000 7500.000 10500.000

16.000	<	16.000
17.000	•	17.000
18.000	•	18.000
19.000	•	19.000
20.000	•	20.000
21.000	<	21.000
22.000	•	22.000
23.000	•	23.000
24.000	•	24.000
25.000	•	25.000
26.000	<	26.000
27.000	•	27.000
28.000	•	28.000
29.000	•	29.000
30.000	•	30.000
31.000	<	31.000
32.000	•	32.000
33.000	•	33.000
34.000	•	34.000
35.000	•	35.000
36.000	<	36.000
37.000	•	37.000
38.000	•	38.000
39.000	•	39.000
40.000	•	40.000
41.000	<	41.000
42.000	•	42.000
43.000	•	43.000
44.000	•	44.000
45.000	•	45.000
46.000	<	46.000
47.000	•	47.000
48.000	•	48.000
49.000	•	49.000
50.000	•	50.000
51.000	<	51.000
52.000	•	52.000
53.000	•	53.000
54.000	•	54.000
55.000	•	55.000
56.000	<	56.000
57.000	•	57.000
58.000	•	58.000
59.000	•	59.000
60.000	•	60.000

3000.000 6000.000 9000.000 12000.000
1500.000 4500.000 7500.000 10500.000

the demands for the goods made by these customer groups, and their consequent need for machine tools. The best documented demands are those upon the armaments industries, which consumed the majority of Greenwood and Batley's tools, and their experience will therefore be considered at some length. It is unfortunately impossible, in the absence of histories of the other major customer industries, to describe the demands which they exercised on Greenwood and Batley with the same precision.

Professor Howard has described the development of arms manufacture during the period from 1850 to the first World War as a process in which 'the speed of technological change... compelled governments to contemplate a total re-equipment of their armies on an average once every two decades, and confronted navies with still vaster problems of expense'.[36] In the Crimea, British and French soldiers were armed with muzzle-loading Minie or Enfield rifles, although the Prussian Army had adopted a breech-loading 'needle-gun' in 1841. The American Civil War, and the Prussian successes in European wars, spurred experiments in other countries with breech-loading rifles, and the British army adopted the Snider rifle in 1864, the French the Chassepot rifle in 1866. In 1871 the British again changed their equipment, adopting the Martini Henry rifle. The next change, to repeating, magazine-feeding rifles, came during the 1880s, with rifles of this type being adopted in 1884 by the Germans, 1885 by the French, 1886 by the Austrians, and 1888 by the British.[37]

36 H.E. Howard, ch.VIII, 'The Armed Forces', New Cambridge Modern History, Vol.XI, ed.F.H. Hinsley. (Cambridge:1962) p.205.

37 B.H. Liddell Hart, ch.XII 'Armed Forces and the Art of War: Armies' New Cambridge Modern History, Vol.X, ed. J.P.T. Bury (Cambridge:1960), pp.304-305.

Similar transformations occurred in ammunition, with the introduction of metal cartridges in the 1870s, and with the inventions of smokeless powder and the small-calibre bullet.[38] The introduction of the machine-gun, although dogged by mishandling and technical difficulties, brought another new weapon to European armies from 1867, when the 'mitrailleuse' gun was adopted by the French.[39] In land artillery similar developments took place, beginning with the conversion of smooth-bore to rifled guns in the Crimea, and the introduction of breech-loading guns, recoil absorbing gun carriages and new explosives for shells later in the century.[40] In naval armament progress was equally swift, both in offensive weapons, beginning with the Armstrong gun of 1855, and in defence, with the introduction of armour-plating.[41] The Whitehead torpedo, manufactured in Britain by Greenwood and Batley, "added another element to the naval battle".[42]

These technical developments in the art of war were accompanied by, and were to some extent the result of, an expansion during this period of the military strength of the great powers, a corresponding expansion of the power of the military leaders, and a growth in expenditure on armaments. The introduction of conscription by all the major powers except Britain led to large increase in the number of men who could be mobilised, and a corresponding increase in the

38 Howard, M.S., op.cit., pp.206-7.

39 Liddell Hart B.H., op.cit., pp.306-7.

40 Howard, M.S. ibid., p.207.

41 Lewis M. ch.XI, 'Armed Forces and the Art of War: Navies' New Cambridge Modern History, Vol.X, ed. J.P.T. Bury (Cambridge:1960) pp.284-5.

42 Howard, M.S. ibid., p.231.

number of weapons needed to arm them.

> "In 1874 Germany had a regular army 420,000 strong and a war establishment of 1,300,000; in 1897 the regular army had increased only by a third, to 545,000, but the war establishment, at 3,400,000 had nearly trebled".

The French war establishment at the latter date was 3,500,000, the Austrian 2,600,000 and the Russian 4,000,000.[43] Between 1874 and 1896 total defence expenditure by the major European powers is said to have increased by slightly over 50%,[44] and it must be remembered that similar increases in expenditure were being undertaken all over the world, in British India, China, Japan, the United States and Latin America. Furthermore, the needs of the armies for transport stimulated expenditure on railway construction, particularly in Russia and Germany.

It is clear that manufacturers of armaments, and of machines to make armaments, were in a fortunate position during this period, as the successes of Krupp, Whitworth and Armstrong, among many others, demonstrate. A rapid rate of obsolescence, combined with an expansion in demand, and an absence of governmental restriction on arms sales, produced what must have seemed at times to be a limitless field for expansion.

This expansion in demand was supplied through a revolution in the methods of manufacture of armaments, the replacement of a traditional craft industry by a factory industry using the most advanced techniques of machining, metallurgy and industrial chemicals.

43 Howard, M.E. ibid., p.217.
44 Howard, M.E. ibid., p.240.

In the light of this market situation, it seems surprising that the machine tool sales of Greenwood and Batley, which were catering for the international manufacturers of arms, both private and governmental, should exhibit such fluctuations as those shown in graphs 5; 2,3,4,5, and 6. A complete explanation of such fluctuations would require an examination of the armament policies of the major European and Eastern countries, material on which does not appear to be readily available. In the case of British manufacturers, both government and private, it is possible to discover the course of demand, and the reasons for the fluctuations in demand which can be observed in graphs 5, 2 and 5, 5. The British experience will therefore be examined at some length, and related to the demand facing Greenwood and Batley. Although the precise timing of foreign demand for new armaments and new machinery for making them was different from the British, as shown above, there is no reason to think that the problems of catering for the demand varied very greatly from country to country, and in default of more detailed evidence the British experience must stand as an example.

Machinery for the manufacture and assembly of interchangeable parts for small-arms was adopted in Britain during the 1850s. The impetus for this development is normally said to have been the report on the use of interchangeable manufacture in the United States published in 1854 by Whitworth and Wallis as a result of their visit to the New York Exhibition of 1852. This was followed by the visit of John Anderson, later superintendant of the Royal Small Arms Factory at Enfield, to the United States, and the

decision by the Government to accept his recommendations for the purchase of machine tools from the United States. The buildings to house this machinery at Enfield were begun in 1855, and by 1857 the factory was making arms at the rate of 1,000 a week.[45] The majority of the equipment was purchased from the United States, or from Belgium, although a Leeds tradition stated that : "Owing to the enterprise of Mr. Greenwood, the interchangeable system of manufacture, an American device, was adopted in England."[46] It is possible that Greenwood did design machines for the Woolwich arsenal while working for Sir Peter Fairnbairn, but he cannot be credited with such a transformation in manufacturing practice as this statement suggests.

The introduction of the machinery at Enfield, on a larger scale than had at first been contemplated, owing to the needs of the Crimean War, forced the traditional craft gunmakers of Birmingham and the Black Country to consider revising their manufacturing methods. The Birmingham Small Arms Trade, an association of 16 leading Birmingham gunmakers, had been formed in 1853, partly to protect the traditional trade from the effects of government competition, but in 1860 very little of the gunmaking process in Birmingham was carried out by machinery.[47] The American Civil War, however, during which "the gun trade... was subject to an enormous increase",[48] stimulated a switch to more modern

45 U.S. Military Commission to Europe, 1855-6. Report by Major Alfred Mordecai. House of Representatives Executive Document, 36th Congress, 2nd Session (Washington:1861)p.10

46 Victoria County History of Yorkshire, Vol.II, (London:191 "Industries: Iron and Hardware" by Mmud Sellors, p.400 fo

47 Allen G.C. "The Industrial Development of Birmingham and the Black Country" (2nd edition, Frank Cass, 1966) pp.107-8.

48 Allen, G.C. op.cit., p.176.

methods, and the members of the Birmingham Small Arms Trade :

> "organised a company in 1861 to erect a factory at Small Heath, and to equip it with machinery capable of producing interchangeable arms comparable to those manufactured at Enfield. 'Stocking' machinery was purchased from Massachusetts and rifling and boring machinery from Leeds, and thus the famous Birmingham Small Arms Company Limited was set upon its long career."49

With the setting up of this factory, both the public and the private sectors of the small arms trade had largely turned to machine made arms, although the large and prosperous sporting gun section of the Birmingham industry continued to make guns by traditional methods.

The implications of these changes for Greenwood and Batley, as manufacturers of machine tools used in these new factories, can be seen in graph 5, 2, showing the purchases by the Government arms factories, and graph 5, 3, shewing purchases by private gunmakers. Although much less is known about the manufacture of heavier guns, and the gun carriages needed for them, than about the manufacture of small-arms, the heavy orders from Woolwich, from the Royal Carriage Factory, the Rifled Ordnance Department and the Royal Laboratory in 1859 and 1860 shew that the introduction of new machine tools to these branches of arms manufacture was being expanded. In the private sector, the expansion of demand for machine tools during the American Civil War is clear in graphs 5, 5. In 1861 the newly established Birmingham Small Arms Company ordered 100 machine tools worth £6,101 from Greenwood and Batley, following this in

49 Allen, G.C. op.cit., p.188.

1862 with orders for 5 more machines worth £450. The major purchaser in this period was however Fraser Trenholm and Co. of Liverpool, and it seems likely that the 348 machine tools worth £30,319, which they bought in 1863, were in fact shipped to the United States, since Fraser Trenholm were not prominent as manufacturers of small-arms. The other major purchases in this period were from makers of larger guns, the Elswick Ordnance Company and Thomas Firth and Sons of Sheffield, the former being involved in the 'Battle of the Guns' between Whitworth and Armstrong at this period.

The ending of the American Civil War produced depression in the private sector of the armaments industry, and through it in sales of machine tools, although the traditional trade, still largely unmechanised, benefited from the Prussian-Danish War of 1865-6 and the Austro-Prussian War of 1866.[50] Although B.S.A. were occupied between 1866 and 1867 in the conversion of 100,000 muzzle-loading Enfield rifles to breech-loaders, using the Snider action, they do not seem to have bought new machinery for this purpose, and the government factories were presumably also well-equipped. Purchases of machine-tools are thus low in this period. Some recovery in the trade came with the Franco-Prussian War of 1870-1871, and Greenwood and Batley received further large orders in this period from B.S.A., and from the two other factory small arms manufacturers, the London Small Arms Company and Westley Richards Limited, and the latter's successor the National Arms and Ammunition Company. After the war "For some years... the two Birmingham firms were busy supplying British and foreign governments with

50 Allen, G.C. op.cit., p.186.

"the new types of breech-loader..." (the small-bore rifle),[51] and the large orders placed by the National Arms and Ammunition Company for machine tools in 1872 show the effect of this demand in an expansion of capacity in the private industry. However, as Allen states :

> "... after 1875 the cloud descended... The leading Continental powers had by that time equipped factories of their own for meeting their needs, and Enfield prove capable of satisfying the peace-time demands of the British services. Consequently the orders received by the trade were insufficient to occupy more than a small part of their plant."52

The National Arms and Ammunition Co., was wound up in 1882, after an attempt by the three leading small-arms companies to share orders had been frustrated by the War Office, and B.S.A. was forced into an early unsuccessful attempt to make bicycles.[53] Sales of Greenwood and Batley's machine tools show a consequent low level of demand during this period.

The private small-arms and ordnance industries, and the Enfield and other government factories, were rescued from stagnation during the next decade, from about 1884 onwards, by the coincidence of the two types of stimulus to demand for arms, a war scare and the decision by the war office to change the pattern of arms. As Allen puts it, during 1884,

> "prospects began to improve owing to the proposed adoption by the War Office of the magazine rifle; and then, in 1885, both the Enfield and the private factories were roused to a sudden activity by the danger of a rupture between Russia and England."54

51 Allen G.C. op.cit. p.218.
52 Allen G.C. op.cit. pp.218-9.
53 Allen G.C. op.cit. p.219.
54 Allen G.C. op.cit. p.219.

The results of this burst of activity can be clearly seen in the sales of machine tools by Greenwood and Batley. Purchases by all the government manufacturing establishments pushed orders from this sector to £27,995 in 1885, and £21,852 in the following year, by far the highest levels reached during the whole period from 1856 to 1900. Similarly in the private sector, orders particularly from the heavy ordnance and shell makers, Armstrong Mitchell, John Brown, and the Nordenfeldt Gun and Ammunition Co. among others, allowed sales to this sector to rise above £10,000 in 1885, 1887 and 1888.

As in the late 1870s, the expansion of capacity in both the public and the private sectors produced a falling-off in demand for new machine tools in the 1890s, although the private sector of the arms business was kept busy by the adoption of the Lee-Metford magazine rifle by the War Office in 1890.[55] Greenwood and Batley continued to receive orders from armaments makers in this country during the decade, although their financial difficulties, during this period, and their difficulties with government purchasers, show that demand was not very buoyant, at least until the outbreak of the Boer War, at the end of the period for which detailed records of the operations of the firm can be used.

It is clear that sales of machine tools by Greenwood and Batley/were closely related to the vicissitudes of demand in the armaments industry, although the firm was to some extent shielded from the shifts in demand which so badly affected the private arms firms in the 1876 to 1884 period by their ability to sell to the ordnance as well as small-arms sectors. Greenwood and Batley were, however, as the

55 Allen, G.C. op.cit., p.266.

graphs show, able to maintain a substantial sale of machine tools to public and private arms buyers in the intervals between the abnormal peaks and troughs of demand which have so far been described. That they could do so is due to the constant innovation by the firm of new methods of manufacture which enabled them to persuade the arms manufacturers to buy their tools, since the old tools were rendered obsolescen together with the replacement expenditure as machines deteriorated in use.

The process of innovation in the small-arms field is extremely difficult to delineate in detail, largely because, even with the reasonably detailed descriptions of the machine given in the Greenwood and Batley order books, such descriptions tend to be concerned with the job that the machine tool will do, rather than with the way in which it will do it Thus a barrel-turning machine sold in 1860 was a different machine from a barrel-turning machine sold in 1880, but the name has not changed; it may be described as a 'No. 2' machine or as being of 'improved pattern', but this does not give enough information to enable any definite conclusion on the pace of technical change to be drawn. However, there is one case in which evidence exists on a technical change in this field which was large enough to render the previous machinery entirely obsolete, and it can be presumed that similar innovations were made in other fields. In evidence to the Morley Committee of 1887, the Select Committee on the Organisation and Administration of the Manufacturing Departments of the Army, two witnesses spoke of the introduction of new barrel-boring machinery into the Enfield Small-Arms Factory. Colonel Henry T. Arbuthnot described in some detail the process by which new machinery was bought for the Factory :

"If I hear of any new machinery which would be of assistance in my particular work I generally go and look at it myself, if it is running anywhere else and I try and find out what their experience has been, and I send the foreman of my tool room sometimes to look at the machine and to give me his technical opinion upon it, and if I think it is desirable to try it at Enfield I ask for authority to purchase one perhaps first, and if it answers then I go in for it more largely. That is very much the case with regard to the barrel-boring machines; that was an invention of a member of the firm of Greenwood and Batley; he first applied it in a factory which he fitted up for the Government of Italy at Terni I saw it and thought the machine worked all right and i appeared tc me to be very good, but the result that he told me they got in Italy appeared to me to be so extraordinarily favourable that I could hardly believe it, but I obtained authority to purchase one machine to try, and I found that he did not over-state the case one bit. I thought perhaps that one machine would not be a fair test, so I got half-a-dozen more, and they all worked just as satisfactorily as the first did, and now the whole of my boring of barrels is done by these machines. I save about ¼ or ½ per barrel, and one man now does the same work as half-a-dozen did before."56

Mr. McGee, manager of the Enfield factory, amplified to the Committee the evidence of his Superintendant. His evidence illustrates not only the high gains of this innovation, but also the difficulty of attributing credit for it to any one person or company.

Q.7754. We have been told that your cost has been reduced, has that come about through your ordering iron nearer the size, or has it partly come about on wages or on improved machinery? — On improved machinery principally.
Q.7755. Who is responsible for designing that improved machinery? — I have had a great deal to do with it. A little while ago we paid 2s. each for drilling gun barrels. We have now introduced a new machine made by Greenwood and Batley which has reduced the cost of that operation to 3d.

56 Minutes of evidence to the Committee on the Organisation and Administration of the Manufacturing Departments of the Army, (P.P. 1867, XIV, 1, Col 5116) (The Morley Committee), Q.7403.

Q.7756. By whom was that designed? -- In the first place it was a Belgian notion, but it was perfected by Greenwood and Batley and ourselves.
Q.7757. I suppose the principal reason for that machine being a success is that you can work with water at from 60 to 70 lbs. pressure to pump the water to clear the swarf? -- That has a great deal to do with it.
Q.7758. Was it the Belgian idea that you should use water for that pressure? -- I think it was Greenwood and Batley's notion.
Q.7759. But was it the Belgian idea that you should work from both ends? -- Yes.[57]

It is thus clear that Greenwood and Batley were able to sell at least some machinery to the arms manufacturers as the result of technical advance rendering the existing machinery obsolete; the Morley Committee was later told of the necessity of selling the old barrel-boring machinery, probably for scrap.[58] Changes of pattern would also, with the specialised machinery used for small-arms manufacture, make it necessary for new machinery to be bought. Replacement expenditure, the purchase of machinery simply because the old had worn out, is difficult to identify from the Greenwood and Batley records, although in a number of cases orders made reference to previous orders, asking for a machine of the same pattern. Both these types of expenditure, that caused by technical advance, and that for replacements, helped Greenwood and Batley to weather the falls in demand caused by peace or the satisfaction of the army or navy with its existing weapons.

In the case of the machine tools sold to the armaments manufacturers in this country, it is therefore possible to identify quite accurately the exact cause of expansion or decline in demand for arms, and its indirect effect on Greenwood and Batley.

57 Morley Committee, q.7751-9.
58 Morley Committee, q.4900 >414

The causes operating to produce orders for machine tools from foreign governments, shown in graph 3, 4, and from foreign private arms manufacturers, shown in graph 5, 6, are presumably much the same in origin as those motivating the British arms manufacturers, although the timing differs. The first major peak in sales, in 1867 to 1872 in the case of the governments, and 1867 to 1871 in the case of the private manufacturers, is clearly related to the Austro-Prussian and Franco-Prussian wars of this period, but in the absence of any detailed studies of rearmament during this period in countries other than British, explanation of the second major peak, between 1889 and 1891 is more difficult. The major peak in 1891, when machine tools worth £34,896 were sold to foreign governments, is largely the result of sales to the Russian Government, but it is not clear why these purchases were made. The construction of the Trans-Siberian railway began in that year, but the majority of the tools sold to Russia were light tools, principally milling machines, together with a number of rifling machines, so it is likely that a small-arms factory was being equipped.

In the remainder of the industrial groups into which Greenwood and Batley's customers can be divided, identificati of the exact causes of changes in demand is a haphazard process. Demand for machine tools is essentially a derived demand, and identification of its causes thus depends on identificati of demand changes for all the industries to which machine tools are sold. In general, the sales by Greenwood and Batley seem to follow the familiar chronology of the period of the Great Depression, (particularly if the double counting caused by the inclusion of Armstrong, Mitchell in the

General Engineering and Hydraulics, Pumps and Cranes groups is discounted, thus removing the boom in these groups in the 1880s). Identification in the way that is possible in the sales to the armaments industry seems impossible to achieve, if only because Greenwood and Batley are in no sense monopoly suppliers to the other industrial groups, as they became in certain fields of armaments machinery. Thus, in the general engineering groups, a fall or rise in demand for Greenwood and Batley's machine tools may be the result of changes in demand in the industry, or of the attractiveness of a particular tool made by the firm, or of some influence undiscernible at this distance.

In this section the industrial and geographical distribution of the customers for the machine tools made by Greenwood and Batley has been investigated. It has been shown that sales to arms manufacturers in this country were largely determined by government rearmament policies, and it has been inferred that similar causes determined the pattern of orders from foreign manufacturers of armaments. Non-arms sales are less easy to ascribe to particular changes in demand conditions in the customer industries, in the absence of detailed information on these demand changes, and because of the more competitive nature of the market for machine tools in these fields.

IV. Market differentiation.

In the previous section the existence of a number of distinct markets for the machine tools of Greenwood and Batley has been asserted. Identification of these markets has however been solely in terms of the geographical location

or industrial involvement of the customers of the firm. In this section, the order and cost data provided by the records of Greenwood and Batley will be examined in order to see whether the market structure which has been described has any other than nominal significance. In other words, did the different markets in which machine tools were sold affect either the profit levels that could be achieved, or the methods needed to penetrate them, or the behaviour of a firm such as Greenwood and Batley which was faced with satisfying the needs of so heterogeneous a selection of customer firms?

A convenient measure of the degree of competition in different markets for machine tools, and the success of Greenwood and Batley in selling to these markets, is the level of profits which could be attained, and maintained over time, in each market. A significantly higher level of profit in one market over some period of time would suggest that Greenwood and Batley was either in a monopoly or oligopoly position in that market, or that it was more efficient in producing for that market than for others. The first topic to be investigated is therefore the profit levels gained by the firm.

Taking first the geographical division of sales, profit levels were in general higher for sales to some foreign countries than for sales to home customers.

Table 5, 8, shows the average profit levels realised, over the whole period from 1856 to 1900, on sales to Great Britain and to the major foreign customer countries.

Country	Average profits as % of sales
Italy	23.0%
Japan	13.9%
China	17.5%
France	13.4%
Austria	12.7%
Russia	10.3%
Germany	6.5%
India	- 2.6
Belgium	- 5.0%
Great Britain	5.7%

TABLE 5, 3. Profit levels on sales to foreign customers, 1856-1900.

Note : The average for Russia and Belgium are reduced by one large loss in each case. Excluding these losses the figures would be 15.1% and 6.3% respectively.

Z-tests for difference of means reveal that, at the 5% level, there are significant differences between the profit levels given in table 5, 3, for Britain and those for several foreign countries, while the difference between some foreign countries are not significant. Thus the differences between Britain and France and Britain and Russia are significant, those between Japan and France and France and Russia are not.

Further evidence bearing on the difference in profit levels on sales to home and foreign customers is provided by a comparison of the profit levels on sales to each of the industrial groupings of customers. The relevant comparisons are in government purchases, private arms companies' purchases, railway companies' purchases, and in the unidentified groups,

since in all these cases a distinction has been made between home and overseas sales. The average profits as a percentage of total value of sales were 8.51% for home government sales, 5.72% for colonial government sales, and 15.04% for foreign government sales. Within industrial groups the same distinction applied: average profits for sales to home private arms manufacturers were 11.73%, for comparable foreign sales 16.67%. For railway companies the figures are, home -13.99% (i.e. losses overall), foreign 18.93%, and for the unidentified groups profits on home sales averaged 8.23%, and on foreign sales 12.75%.

There are a number of possible explanations for this divergence in profit levels, and they will be considered in turn. Firstly it is possible that the 'profit' on foreign orders includes within it some element of transport cost. However, it appears from the order books that in normal circumstances prices were quoted free on board at British ports (or free on rail at Leeds for home orders). Only exceptionally were prices quoted c.i.f., one example being an order for machine tools for a Russian customer where alternative prices were given according to the possibility of rail or sea transport. Normally, therefore, the price quoted would include only a small element of transport cost, and it seems reasonable to reject the first hypothesis that the observed differences in home and foreign profit levels were caused by this factor. A second justification for rejecting this hypothesis is that there is no significant difference in profit levels between sales to nearby and to distant foreign countries; the difference in profit levels between France and Japan, or France and Russia shown in table 5, 8, is non-significant. Had transport costs been

included in price, it would have been likely that a differential would be observable between close and distant countries; its absence is at least negative confirmation of the rejection of this first hypothesis.

A second hypothesis to explain the difference between profit levels on home and foreign sales would be that the firm used a different pricing policy, perhaps deliberately securing a higher mark-up on foreign sales to compensate it for the volatility of the foreign market referred to above, or alternatively reducing the quality of goods ordered by foreign customers so as to obtain a higher profit margin. An explanation in these terms would require that, for a given machine, the profit level obtained on a home sale would be smaller than that obtained on a foreign sale. It is thus possible to test, for each sub-type of machine, to see whether there is a significant difference in the profit level as a percentage of the value of the machine sold, between home and foreign sales. One difficulty in such a test is the heterogeneity of the machines even within the sub-types by which they are described, a factor that produced very large variances for the calculated mean profits. However, working with these variances and applying again a t-test for difference of means, no machine sub-type shows a significant difference at the 5% level between profit levels on home and foreign sales. Had this second hypothesis been true, that home and foreign sales would show different profit levels for comparable machines, then at least some significant differences should have been found, even with the large variances which have been mentioned. It seems reasonable, therefore, to reject the hypothesis that the firm had some policy which resulted in foreign customers being charged more for their machine tools than were home customer

The third hypothesis which would explain the observed difference in profit levels between home and foreign sales is that the mix of machines ordered by foreign customers was different from that ordered by home customers, and that sales to foreign customers were composed of machines on which a higher profit level was obtained. In other words, the hypothesis is that the difference was not so much a result of the location of the customer but of the machines which he was buying. In order to test this hypothesis it is necessary to examine firstly the mix of machine tools ordered by home and foreign customers, and secondly the profit levels obtained on different types of machine tools sold.

Table 5, 9, sets out the numbers of machine tools sold to home and foreign customers, broken down by the types of machines that were bought. It refers to all machines for which more than 10 home and 10 foreign orders were received during the whole period from 1856 to 1900, that is the major types of machine tools sold by Greenwood and Batley.

A chi-square test on the data presented in table 5, 9, permits the rejection, at the 5% level, of the null hypothesis that the two groups, machine tools sold to home and to foreign customers, are similar in mix. (X^2= 491.99 with 16 degrees of freedom). Less rigorously, it is clear that certain types of machines were sold in much greater frequency to foreign customers than the proportions sold in total would suggest. Thus in total, taking the groups of machines given in table 5, 8, of the 11,474 machine tools included 61.5% were sold to home customers, 38.5% to foreign customers. Table 5, 10, shows the data for table 5, 9 converted into percentage form, with the machine tools ranked according to the proportion sold to home customers.

Machine Type	Number sold to Home Customers	Foreign Customers	Total
1. Lathe	1,757	837	2,594
2. Planing machine	145	48	193
3. Drilling machine	823	293	1,116
4. Milling machine	2,255	1,644	3,899
5. Grinding machine	98	41	139
6. Shaping machine	156	180	336
7. Slotting machine	124	114	238
9. Press	51	15	66
10. Wheel- and gear-cutting machine	83	29	112
15. Boring machine	329	268	597
16. Punching and shearing machine	62	53	115
17. Component parts orders	335	422	757
21. Slitting machine	123	155	278
25. Screw-making machine	366	106	472
27. Rifling machine	132	165	297
33. Cutter-sharpening machine	125	16	141
35. Bolt-making machine	90	34	124
Totals	7,054	4,420	11,474

TABLE 5, 9. Numbers of machine tools sold to home and foreign customers, broken down by type of machine tool, 1856 to 1900.

Machine Type	% Sold to Home Customers	% Sold to Foreign Customers
33. Cutter-sharpening machine	89	11
25. Screw-making machine	78	22
9. Press	77	23
2. Planing machine	75	25
13. Wheel- and gear-cutting machine	74	26
3. Drilling machine	74	26
35. Belt-making machine	73	27
5. Grinding machine	71	29
1. Lathe	68	32
4. Milling machine	58	42
15. Boring machine	55	45
16. Punching and shearing machine	54	46
7. Slotting machine	52	48
6. Shaping machine	46	54
17. Component parts	44	56
21. Slitting machines	44	56
27. Rifling machines	44	56

TABLE 5, 10. Conversion of table 5, 9, into percentage form, summing across columns.

Note : The line drawn between lathe and milling machine figures indicates the average proportions found in the totals, that is 61.5:38.5.

It is thus apparent that there were significant differences in the mix of machine tools sold by Greenwood and Batley to home and to foreign customers. It is possible, therefore, that this difference may explain the observed difference in profit levels obtained from these two groups of customers.

To confirm this, it would be necessary to demonstrate that foreign buyers were buying tools on which higher profit margins were charged. A test of this would be to examine whether, for type of machines, profit level is correlated with a tendency for a machine to be sold abroad. To test this the machines listed in table 5,10, were ranked according to the proportion sold to home customers, that is in the order in which they are given in that table. They were further ranked according to profit level, that is the type with the highest average profit, in fact bolt-making machines, with an average profit of 29%, was ranked highest. The hypothesis would suggest that a correlation analysis between these two sets of ranks should produce a correlation coefficient which would be positive and significantly large. In fact computation of the Spearman rank correlation coefficient gives a value of -0.35; this is non-significant and has a sign opposite to that predicted. It would thus seem that no credence can be attached to the hypothesis that foreign sales were of machines which had higher profit levels than had machines sold to home buyers.

The difficulty remains of explaining why this observed difference in profit levels occurred, if all the hypotheses so far advanced must be rejected. It is conceivable that the explanation lies in a mixture of the second and third hypotheses (with conceivably a slight influence from the first). In other words, the joint effect of the sale to foreign markets of a selection of machines slightly different from those sold to home buyers, combined with a slight tendency to charge higher profit margins on foreign than on home sales, combined perhaps with an element of transport charges in foreign prices, may provide together an

explanation of the difference in profit levels, although individually none of these tendencies can provide such an explanation. It is further possible that the testing of these hypotheses on the bread groupings of machines listed in tables 5, 9, and 5, 10, has, because of the lack of homogeneity within the types, obscured the explanation.

One can combine the hypotheses by examining the profit levels obtained on home and foreign orders for sub-types of machines, within those groups which were sold predominately to home or predominantly to foreign buyers. Specifically, all sub-types of machines of which more than 50 were sold were selected, a total of 34 sub-types, (Three sub-types, which sold more than 50 in total, but less than 10 to one of the categories of home and foreign buyers, were excluded.) The machines within these groups were then classified according to whether they were sold to home or to foreign customers, and average profit levels were calculated for each type. These profit levels were then summed over each of the four divisions, home sales in predominantly home sold sub-types, foreign sales in predominantly foreign-sold sub-types, home sales in predominantly foreign sold sub-types, and foreign sales in predominantly home sold sub-types. Averages were then calculated for each of these four divisions. If both the hypotheses were interacting, one would expect that the highest profit levels would be found in the foreign sales in the predominantly foreign sold group, and the lowest profit levels in the home sales in the predominantly home sold division, with the other two divisions in between' their order depending on the relative importance of the explanation in terms of mix and the explanation in terms of different pricing policies.

The results of this analysis were :

Group		Mean Profit Level
Predominantly home sold (22 sub-types)	Sold to home buyers	9%
	Sold to foreign buyers	13%
Predominantly foreign sold (12 sub-types)	Sold to home buyers	10%
	Sold to foreign buyers	16%

These figures confirm the suggestion that the explanation for the higher profit levels lies in a mixture of the different types of machines ordered by foreign buyers, and a tendency for orders to foreign buyers to be higher priced regardless of machine type. The difference between the extreme figures, 9% and 16% is statistically significant at the 5% level for a one tail test, ($z = 1.88$) which is used since the direction of the difference is predicted. It would also appear, although the differences are not significant, that the influence of different pricing for foreign orders is slightly higher than the influence of the different mix of orders, since the two central figures, 13% and 10%, are in the order shown.

It is thus apparent that Greenwood and Batley sold their machine tools in two markets which were distinguished not only by their geographical location, but also by the level of profits which the firm could attain. It is however, conceivable that the true distinction between the markets in which Greenwood and Batley was involved is not in terms

of location of the customers, but is the result of differences in profit levels to be obtained in sales to different industries. It is conceivable, for instance, that if higher profit margins were obtainable on sales to customers involved in the manufacture of armaments, then the importance of such sales, particularly to foreign buyers, could produce the effect which has hitherto been ascribed to the influence of differences between home and export markets. Calculation of the average amount of profit as a percentage of total sales to each industrial grouping of the customers of the firm gives some support to such an explanation. Table 5, 11, sets out the results of such a calculation. Calculation of the average profits on the five 'armaments' groups shows that these profits, at 11.9%, are considerably higher than the average profits for the remainder of the industrial groups, which in fact show an average loss of 1.5%. (Average profit on the 11 groups where overall profits were made is 7.3%). Average profits on sales to the home arms groups were 9.5%, and on the remaining home groups 3.7%. There would therefore seem to be some justification in arguing that Greenwood and Batley were successful in obtaining higher profit levels on foreign sales, and also on sales to producers of armaments, although it is impossible to estimate the relative contribution of these two factors to the differential profit levels which have been observed.

It now remains to explain why profit levels should have differed in the ways which have been considered, and how this pattern of involvement in what can be considered as two different markets for machine tools affected the profitability and the operations of Greenwood and Batley.

Industrial Group	Profits as % of sales	Number of orders
1. British Government	7.05	634
2. Colonial Governments	5.72	269
3. Foreign Governments	16.05	743
4. Armaments : Home	11.82	669
5. Armaments : Foreign and Colonial	16.67	115
6. Machine tools : Home	2.91	91
7. Hand tools : Home	-7.53	81
8. General engineering : Home	4.71	171
9. Textile Machinery : Home	-1.67	80
10. Electrical Machinery : Home	-13.59	81
11. Sewing Machines : Home	5.04	46
12. Agricultural Machinery : Home	2.57	31
13. Cycles : Home	-6.97	48
14. Steam Engines : Home	2.20	225
15. Railways : Home	-11.05	84
16. Railways : Foreign and Colonial	18.93	43
17. Iron and Steel Products : Home	3.13	30
18. Shipbuilding : Home	-14.38	8
19. Hydraulics, Pumps and Cranes : Home	9.32	201
20. Printing and Paper Machinery : Home	-33.37	9
21. Locks : Home	-19.42	7
22. Other identified	4.33	41
23. Unidentified : Home	1.17	244
24. Unidentified : Foreign and Colonial	13.17	590

Table 5, 11. Profits as a % of total sales, broken down by industrial group of customers, 1856 to 1900.

Note : This table is based on all orders for which both price and cost are given.

N = 4170.

able to obtain

The explanation of how Greenwood and Batley were/higher profits on sales to some customers than to others must lie in differences in the competitive position in different markets. There is a paucity of evidence on the degree of competition in the markets for machine tools, but it would seem likely that the export trades, particularly to countries without their own developed engineering industries, would be less competitive than the market within Great Britain, in which a large number of engineering firms were competing. Within Great Britain, also, there is considerable evidence, some of which was considered in the chapter on the structure of the industry, that machine tool firms, although willing to make almost any tool required, preferred to specialise in tools for a particular trade, and to build up connections with that trade in an effort to ensure a regular flow of orders. Thus the market for, for instance, machine tools for the manufacture of printing machinery might be less competitive than the market for, for instance, machine tools for engine building, simply because, as the market for tools for printing machinery was smaller, not all manufacturers would build up the connections with the printing trade which would enable them to design suitable tools or modifications of tools for this particular purpose. It is likely that this would apply with particular force to the sale of machine tools for arms partly because of the relatively restricted number of customers for such machinery, and partly because of the specialised nature of many of the tools, whether because of their complexity, as with some mass-production machinery, or their size, as with large gun-boring lathes, which only a small number of firms could undertake to make.

In the case of Greenwood and Batley, these theoretical considerations suggesting that the market for arms-machinery was not perfectly competitive are borne out by direct evidence on the relationship between the firm and the British government as a purchaser of machinery. The government, in its desire to build up a stable relationship with a small number of firms, is acting in much the same way as that described by Mr. Trebilcock in his study on the supply of cordite.[59] In the Report and Minutes of Evidence of the 1887 Committee on the Organisation and Administration of the Manufacturing Departments of the Army, it was stated that tenders for the supply of engineers machine tools for the army were normally requested from 27 firms, and for special machine tools 11 firms were approached. Colonel Barlow, the superintendent of the Royal Laboratory at Woolwich, which supplied ammunition for the army and navy, described to the Committee the system that was adopted :

> Q.2723 You were saying that the Manager and Assistant Manager designed all your machinery; after having designed it, what course do you take in obtaining new machinery? --- One of two courses is taken, sometimes we make the machinery in a great measure in the department or else modify the old plant, which not infrequently happens; otherwise it is put out to contract through the Director of Contracts.
>
> Q.2724 Do you ask two or three different firms to contract for it? --- As a rule we endeavour to put as many names in as we can. I would like to mention that there is one maker to whom we generally give the plant for small arms cartridge manufacture, namely, Greenwood and Batley, because they first made this plant, which is rather a specialty of theirs; but as a rule we endeavour to put a large number of names on our contract paper.

59 R.C. Trebilcock "A 'Special Relationship' - Government, Rearmament and the Cordite Firms". Econ. H.R., 2nd ser. XIX, 2, Aug. 1966.

Q.2725 May I ask why you went to Greenwood and Batley? --- You are going back too long before my time, but I think I may say that they are a firm who are very well known in the trade as manufacturers of that class of plant.

Q.2726 Do I understand you to say that you went to them because they had made for you in previous years? --- We went to them partly on that account, but you must remember that I put other names on the paper even in that case; I think, as a matter of fact, you will find that Greenwood and Batley have got our orders for the small arms machinery. In our last contract we put in other names; the thing was gone into with the Director of Contracts, and, on the whole, we thought it was best to go to them.

Q.2727 When you put other names forward and allow them to tender, do you take the lowest tender? --- Not invariably; other circumstances may come in and the lowest tender may occasionally be cut out by time; but, as a general rule, unless we can show cause against we take the lowest."60

It is clear that in this, and presumably in other fields of government purchases, a free market in the supply of machine tools did not exist, the opportunity to tender for government contracts being restricted. Of course, the restriction of the market in this way does not necessarily imply that the prices charged will be inflated; the object, after all, of competitive tendering is to obtain for the purchaser the lowest possible price. There is however evidence that the restriction of the opportunity of tendering to a small number of machine tool firms, all of them known to each other, allowed these firms, by collusion, to share the market and to fix prices to suit themselves. Evidence on market-sharing and price fixing agreements is normally elusive, since the participants in such arrangements naturally preferred them to remain secret, but in this particular case of machine tool supply to arms manufacturers some evidence

60 Morley Committee, op.cit.

has survived, in the form of a private out-letter book belonging to the firm of James Archdale and Co. of Birmingham. In view of the exceptional evidence contained in this correspondence on market sharing and price fixing arrangements, it will be quoted at length. It should be remembered that the letters are those sent by Archdale's; the replies have not been preserved.

October 7th. 1889 To Messrs. Wm. Muir and Co.[61]
Dear Sir, We have enquiries from Enfield for the following - Will you please say per return what enquiries you have so that we may arrange matters. Yours truly.
1 Vertical Drilling Machine £30 [62]
2 Capstan Machines £16
2 10" lathes £43
5 ...(illegible) drilling machines £28
10 Cross milling machines £11
5 Cross milling machines £12
11 Back-geared cross millers £13
1 Screw capstan lathe £18
2 Trimming presses £42
4 Cross millers £14
2 Capstan Lathes £44
2 Drilling machines £24
10 Edge milling machines £15
1 Shaping machine 12" £23
1 6" shaper £19
2 Shaping Machines £22

Oct 7th 1889 To Arthur Greenwood Esq.[63]
Dear Sir, We have enquiries from Enfield for the followin and will you please say per return what enquiries you have, so that we may arrange matters. Yours truly.
(There follows the list of machine tools as in the previous letter)

Oct 12th 1889 To Arthur Greenwood Esq.
Dear Sir, Thanks for your wire. We have wired "our Manchester friend", and he agrees to be at your office on Wednesday afternoon at 3 o'clock. Our Mr. Archdale will also attend at same date and time. Yours truly.

61 A machine-tool firm in Manchester. Muir formerly worked for Archdales, according to Mr. Clements, a former employee of James Archdale and Co.
62 These numbers presumably refer to patterns.
63 Chairman and Managing Director of Greenwood & Batley Ltd

Oct 14th 1889 To Messrs Wm. Muir and Co.

Dear Sirs. We thank you for yours of the 12th inst. We wrote you on Saturday appointing the meeting in Leeds for 3 p.m. on Wednesday at Mr. Arthur Greenwood's office. We note that you are quoting £14.10. Od for the 12 drills to Smallheath.[64] We are quoting £15 each delivery 3 months. We wired you this afternoon to kindly send us tonight certain the prices you are quoting Smallheath for the special lathes and drills they require. We are holding over our quotation until we know this. Yours etc.

Oct 15th 1889 To Messrs Wm, Muir and Co.
Dear Sirs, Thanks for yours of 14th inst. We have quoted prices etc as below

4	6" backgeared screwcutting lathes	£60 each	4 weeks time
4	6" plain lathes for cylindrical part of bolt	£45 each	14 weeks time
3	6" plain lathes for inside of belt handle	£45 each	14 weeks time
5	6" copy turning lathes	£55 each	14 weeks time
2	8" spherical rest lathes, for rough finish turning knee	£45 each	14 weeks time
2	6" compound slide rest lathes for rough finish turning shank	£38 each	14 weeks time
12	Quick speed drills	£15 each	12 weeks time
3	Horisontal drilling machines	£40 each	14 weeks time
1	Horisontal drilling machine	£40 each	14 weeks time.

We confirm our wire of thie morning : "Mr. Archdale will meet Mr. Muir at 2 o'clock tomorrow afternoon Queen's Hotel Leeds". They can then proceed to Mr. A. Greenwood's office, the meeting being fixed for 3 o'clock. Yours etc.

Oct 21 1889 To Arthur Greenwood Esq.
Dear Sir, We quoted B.S.A. Co. Smallheath on 14th inst. for machines as follows:-
(There follows list as in previous letter, identical except for two small changes in times of delivery).

64 The Birmingham Small Arms Co. factory at Smallheath, Birmingham.

Nov 7th 1889 Alfred Muir Esq.
Dear Sir. We thank you very much for yours of 6th. Up to the present we have no orders from Enfield. When we hear anything we will at once let you know. Yours etc.

Nov 12th 1889 To Arthur Greenwood Esq.
Dear Sir, The only orders at present received from Enfield by us are :
2 10" lathes at £146 each
1 6" shaper at £42
2 Automatic Bolt-shaping machines at £50 each
1 12" shaper at £70
What have you received. Yours respectfully etc.

Nov 13th 1889 To Alfred Muir esq.
Dear Sir, The only orders ar present received from Enfield by us are : (list as in previous letter)
Have you received any further orders? Yours etc.

Nov 14th 1889 To Arthur Greenwood Esq.
Dear Sir, We thank you for yours of 13th inst. Of course we are sorry we have not got a better share of Enfield work but at the same time are glad to think the prices have been kept up. We received intimation this morning that our tender was declined. If you will kindly favour us with a specification of lathes required we shall have pleasure in quoting or at any rate considering whether we can put in for them or not. — Per same post we send you our catalogue. Yours etc.

Nov 16th 1889 To Arthur Greenwood Esq.
Dear Sir, Many thanks for your specification returned herewith. As at present situated we could not quote for the tools required. We thought perhaps you were requiring a largish quantity of 6" or 8" lathes and then we could have given you a quotation. You will also do better by buying the stocks and dies direct from the maker (we do not make them). Yours respectfully

Nov 16th 1889 To Arthur Greenwood Esq.
Dear Sir, Yours of 14th. re K. and Co. Ltd.[65] The matter we fear will prove rather difficult to adjust to our mutual satisfaction. We don't like the plan of accepting commissions - if you get the order we do not wish any commission. We merely wanted to know if you

65 Presumably Kynoch and Co. Ltd., small arms ammunition makers.

were tendering and our object was to try and see if we could not keep up the prices. We have already tendered for cutting and cupping and drawing machines for the case and bullet envelopes for .303 cartridges. We now see the difficulty of the position - as your machines probably are not similar to ours of course the prices cannot be similar. Of course we cannot ask you to shew your hand as we should not like to do so ourselves. We fear in this case each must stand on his own merits but if you can throw any light on the matter we shall be pleased to hear from you. You can rely on us acting square. Yours etc.

Nov 20th 1889 To Alfred Muir Esq.
Dear Sir, We thank you for yours of 19th. The Gas Block (? partly legible) machine shall be put in hand. Sorry to hear you have been laid up. We have heard from Leeds and of course are vexed we have fared so badly but at same time are glad to have been to some extent the means of keeping up the prices. Yours etc.

May 16th 1890 To Mr. Wurtzburg[66]
Dear Sir, We have an enquiry from Sparkbrook[67] for 20 cross millers, heavy pattern...(illegible). Muir is going to quote £62. We thought of quoting abt £60. As yourselves and Muir gotthe bulk of the last Enfield enquiry. We think we ought to have this and will you kindly say what enquiries you have got and what you have to propose in this matter? We have also an enquiry for a few other tools as herewith....(illegible possibly 'estimated'), but as Muir has not received and the machines are specified to be of our make we concluded that ourselves only have received it.
1 machine ....(illegible) shaping.
2 ...(illegible) copy millers.
3 4 spindle drills
3 2 spindle drills
3 1 spindle drills
6 edge milling machines ...(illegible)
6 edge milling machines small
3 slot drills
As the tenders have to be posted on the 21st inst there is no time to lose and hoping to hear from you per return. Yours etc.

66 A Managing Director of Greenwood and Batley Ltd.
67 The Royal Small Arms Factory at Sparkbrook, Birmingham.

May 20th 1890 J.H. Wurtsburg Esq.
Dear Sir, We thank you for yours of 19th inst. We rather demur however to your claim to the 20 cross millers. You and Muir had the bulk of the last order to our almost ...(illegible) exclusion. We think therefore you ought to give us a little advantage in this case. The enquiry for 20 millers is worth more than our other enquiry as there are 20 of a kind. However we will quote £60...(illegible) as you... (illegible) abide by the result. We understand Mr. Muir will quote £62. Yours.

May 20th. To Alfred Muir Esq.
Dear Sir, Mr. Wurtsburg is going to quote £60 for the cross millers and we are going to quote the same. We understand you will quote £62. Yours etc.

June 4th 1890 To J.H. Wurtsburg Esq.
Dear Sir, We beg to advise you that we have received the Sparkbrook order for 20 cross millers at £60 ea. in addition to the special machines that we specified to be of our make and of which we advised you. Yours et

June 17th, 1890 To J.H. Wurtsburg.

Machines for B.S.A. Factory Sparkbrook	Price each	Time dela
1 Machine radial drilling	135	6 we
1 Machine drilling, double geared (heavy)	80	3 mo
1 Machine shaping 15" stroke	170	3 mo
*1 machine spotting Barrel	140	3 mo
1 machine special, for drilling cleaning rod hole	-	-
3 machines drilling, horizontal double spindle for butts and fore-ends	50	3 mo
1 machine drilling and tapping butt plate screw holes letting in...(illegible) of butt plate	-	-
3 Machines milling, Archdales copy	60	3 mo
*1 Lathe turning barrel finish	100	3 mo
2 machines clamp milling for end of barrel	-	-
1 machine facing for end of barrel	-	-
7 machines drilling, horizontal, 3 spindles for drilling barrels	-	-
2 lathes for drilling special to centre barrel	-	-
1 set Pump and accumulator for screwing barrel plant with fitting complete	-	-

* these prices are same as had by us before for these machines. Note, tenders to be posted from here on Thursday 20th inst.

June 17th 1890 To Mr. Wurtzburg.
Dear Sir, We now enclose prices and time delay we propose putting in. We have ascertained that there are some half dozen firms cutting in for the machine tools and consequently we shall not stand very much chance for them. —— We find that only you and ourselves are invited to tender for the remainder. As we shall not stand much if any chance for the ordinary machine tools we think we ought to have the barrel finish turning and the barrel spotting. They are required to be precisely as last made by us but with some alterations and improvements affected by themselves —— If you will please let us know what amts. to put down for the other machines we will carry out your wishes. We think however that there had better not be too great a difference or it might look suspicious bearing in mind the low prices you have sometimes lately put in. — We hope to hear from you on Wednesday as the matter is urgent. Youre etc.

The letters which have just been quoted cover a period of just under one year, but it is clear from the tone of the correspondence that the collusion in price-fixing and market sharing which they reveal was a continuing, and, in the case of these three firms, an efficiently organised practice. It should be emphasised that Archdale's, Muir's and Greenwood and Batley were among the most reputable and most successful makers of machine tools at this period, and judging from their records and advertisements all had a wide sale for their tools both at home and abroad. That the arrangement revealed in the letters was unknown to the government buyers of machinery is confirmed by the evidence of Colonel Barlow, given to the Select Committee sitting in the same year as these letters were being written. The three firms involved seem to have been satisfied that the arrangement did in fact contribute to "keeping prices up", and it seems reasonable to conclude that such arrangements are at least partially responsible for the higher profit levels which Greenwood and Batley were, as has been shown, able to obtain on their orders for arms machinery.

It is further likely, although no direct evidence for this exists, that such price fixing agreements operating in the home market helped to keep up prices in the export field. The prestige attached to supplying the British government must have helped such firms as those named in this correspondence to secure orders from foreign governments, (advertisements in trade journals make a special point of mentioning that a firm has supplied the government) and the maintenance of prices on home orders in this way must have allowed the firms to keep up similar or even inflated price levels in export markets.

It should of course be emphasised that such arrangements were probably viable only in the making of machine tools to do a specialised task, as the letter of June 17th 1890 about tools for B.S.A. suggests. However, such orders were obviously of great importance to the firms taking part in the arrangement, and it seems likely that in other specialised fields of machine tool building, similar arrangements, and a similar dependence of machine tool firms on them, may have existed. For Greenwood and Batley, much of whose profits came from sales of machine tools to arms makers, the arrangements revealed in this correspondence must have been extremely important in maintaining profit levels, especially since the profit margins revealed in their records for other machine tools were so slender.

It is further likely, although no direct evidence for this exists, that such price fixing agreements operating in the home market helped to keep up prices in the export field. The prestige attached to supplying the British government must have helped such firms as those named in this correspondence to secure orders from foreign governments, (advertisements in trade journals make a special point of mentioning that a firm has supplied the government) and the maintenance of prices on home orders in this way must have allowed the firms to keep up similar or even inflated price levels in export markets.

It should of course be emphasised that such arrangements were probably viable only in the making of machine tools to do a specialised task, as the letter of June 17th 1890 about tools for B.S.A. suggests. However, such orders were obviously of great importance to the firms taking part in the arrangement, and it seems likely that in other specialised fields of machine tool building, similar arrangements, and a similar dependence of machine tool firms on them, may have existed. For Greenwood and Batley, much of whose profits came from sales of machine tools to arms makers, the arrangements revealed in this correspondence must have been extremely important in maintaining profit levels, especially since the profit margins revealed in their records for other machine tools were so slender.

APPENDIX 5, 1.

Machine tools made by Greenwood and Batley, Ltd. to 1900

The machine tools are listed by main types, e.g. 'lathe', and then by sub-types, e.g. 'screwcutting lathe'.

1. LATHE.

1. Blanchard copying
2. Polishing or surfacing
3. Screwcutting
4. Hollow-spindle
5. Turret or capstan
6. Roller
7. Fluting
8. Surfacing and screwcutting
9. Double
10. Copying
11. Boring
12. Gap
13. Eccentric
14. Brass finishing
15. Grinding
16. Disc and surfacing
17. Chuck
18. Tyre turning and boring
19. Break
20. Annular
21. Hollow-spindle and capstan
22. Spinning
23. Bushing
24. Wheel
25. Cutting off
26. Face
27. Drilling
28. Quadruple capstan rest.

2. PLANING MACHINE.

1. Reversing
2. 'Jim Crow'
3. Circular
4. 'With two tools'
5. Two tools boxes, two tools each
6. Circular planing or ending
7. Roller pad
8. Vertical
9. Profile
10. Stud planing
11. Screw planing
12. Side planing
13. Rack planing

Appendix 5, 1, continued :

4. DRILLING MACHINE

1. Pillar
2. Radial
3. Multiple
4. Wall
5. Column
6. Horisontal
7. Portable
8. Hollow upright
9. Bench
10. Slot drilling
11. Drilling and boring
12. Horisontal drilling and borin
13. Capstan
14. Mitrailleuse
15. Horizontal rotary
16. Horizontal drilling and milli
17. Rack pillar
18. Mortice
19. Armature

5. MILLING MACHINE

1. Clamp
2. Edge
3. Screw
4. Universal
5. Sand miller
6. Copy
7. Common
8. Independent
9. Straight
10. Vertical
11. Pointing
12. Rotary
13. Double
14. Face
15. Point
16. Rotating
17. Profiling
18. Cutter
19. Vertical universal straight
20. Cam
21. Multiple spindle.
22. Horisontal
23. Keyway
24. Worm wheel
25. Cross
26. Capstan
27. Mortice
28. Thread
29. Milling and planing.

6. GRINDING MACHINE

1. Twist drill grinder
2. Surface
3. Internal
4. Cylindrical
5. Sand
6. Cutter
7. Copy
8. Spindle
9. Copy cutter
10. Automatic emery
11. Shell
12. Mill
13. Tool
14. Grinding and lapping
15. Universal
16. Grinding and polishing
17. Vertical

Appendix 5, 1, continued :

6. SHAPING MACHINE

1. Flat and circular
2. Circular
3. Flat
4. Universal
5. Milling
6. Double
7. 'Kinders patent'
8. Straight
9. Incline
10. Bevel wheel

7. SLOTTING MACHINE

1. Horizontal
2. Fellers
3. Double upright
4. Vertical
5. Compound
6. Box screw

8. MOULDING MACHINE

1. Moulding and shaping

9. PRESS

1. Hydraulic
2. Screw
3. Punching
4. Pressing machine

10. SCREWCUTTING MACHINE

11. STAMPING MACHINE

12. CAM-CUTTING MACHINE

13. WHEEL- AND GEAR- CUTTING MACHINE

1. Wheelcutting and dividing
2. Bevel
3. Helical
4. Worm

14. PLANING AND CUTTING MACHINE

15. BORING MACHINE

1. Horizontal
2. Double finishing
3. Vertical
4. Multiple
5. Double
6. Boring and ending
7. Double horizontal
8. Barrel finish
9. Boring and tapping
10. Capstan horizontal
11. Mitrailleuse
12. Mitrailleuse capstan
13. Boring and milling
14. Barrel boring
15. Horizontal boring and milling
16. Hollow spindle

Appendix 5, 1, continued :

16. PUNCHING AND SHEARING MACHINE

1. Punching and trimming
2. Shearing
3. Punching
4. Circular shearing
5. Guillotine
6. Rivet shearing

17. CO PONENT PARTS

ordered for other machine

18. TAPPING MACHINE

1. Horizontal
2. Vertical

19. SCREWING MACHINE

1. Capstan
2. Bolt and nut
3. Screwing and lapping
4. Screwing and turning

20. HORIZONTAL BORING, CUTTING AND DRILLING MACHINE

21. SLITTING MACHINE

1. Screw

22. BROACHING MACHINE

23. TURNING MACHINE

1. Trunnion

24. DIVIDING MACHINE

25. SCREW-CUTTING MACHINE

1. Capstan
2. Rotary
3. No. 1
4. No. 2
5. No. 3

26. SAWING MACHINE

27. RIFLING MACHINE

1. Capstan rest
2. Martini-Henry

Appendix 5. 1, continued :

30. NUT AND BOLT MAKING MACHINE

31. THREADING MACHINE

32. PROFILING MACHINE
    1. Horizontal

33. CUTTER-SHARPENING MACHINE
    1. Milling

34. CHASING MACHINE
    1. Mitrailleuse

35. BOLT-MAKING MACHINE
    1. Nut and bolt
    2. Nut, bolt and rivet
    3. Bolt and rivet
    4. Nut
    5. Rivet

37. TWIST-DRILL CUTTING MACHINE
    1. Double-headed

39. UNIVERSAL CUTTER MILLING AND GRINDING MACHINE

40. FILE GRINDING MACHINE
    1. Flat
    2. Round

41. CHAMBERING, SCREWING AND SHAPING MACHINE

42. GUNBORING, TRACING, RIFLING AND LAPPING MACHINE

43. BORING, TURNING AND RIFLING MACHINE

44. GEAR-CUTTING MACHINE

N.B. The numbers are those used in the recording and processing of the data. Omitted numbers refer to alterations, second-hand machines and odd attachments.

APPENDIX 5, 2.

List of records of Greenwood and Batley Ltd.

(The records listed below are now in the possession of Leeds Public Library, with the exception of items 17 and 18).

1. Time ledgers. c.100 volumes. 1856-1966.

2. Order books. 60 volumes. 1856-1920.

3. Carriers' delivery books. c.30 small books. c.1880-c.1920.

4. Photographs indexed by machine type Book A1 c.1860-c.1880
Book B1 c.1880-c.1903
c.1904-c.1915

5. Sectional order books. c.25 volumes. c.1880-c.1915.

6. Cost and time ledgers (Tool department). 11 volumes from 1911 onwards.

7. Letter books. 3 volumes from period 1870-1910, incomplete.

8. Letter book of the North Wortley Conservative Association, 1885-1895.

9. Patents. 23 boxes of patent specifications.

10. List of photographs (see 4 above). Indexed by works number. 3 volumes, 1857 to 1966.

11. Sectional ledgers. c.50 volumes.

12. Departmental cost accounts. 1 volume, 1910-1911.

13. Cash and cheque record. 2 volumes from 1980-1985.and 1907-

14. Costs of sundries ledgers. 10 volumes from 1910-1914.1908

15. Catalogues :

a. English circulars, 1-160. no date.
b. English circulars, 161-327. no date.
c. English circulars, 328-500. no date.
d. English circulars, 501-660, dated c.1902-1905.
e. Two further volumes of English circulars, from 1930s.
f. German catalogue, c.1900-1910.
g. Catalogue of machine tools, c.1920-30.
h. Machine tool catalogue, no date.
i. Illustrated catalogue of milling machines, c.1906.
j. French 'catalogue illustre des machines a fraiser', 190'
k. Illustrated catalogue of bolt and nut machinery, 1896.
l. Illustrated catalogue of machine tools, 1906.
m. Catalogue of textile machinery, c.1920s.
n. Catalogue of oil mill machinery, c.1920s.
o. English circulars, 661-821, c.1905-c.1910.
p. French catalogue, c.1920s.

Appendix 5, 2, continued :

16. Two volumes, described as English circulars, but in fact containing press cuttings, advertisements etc. relating to Greenwood and Batley.

17. Minutes of the Board of Directors, 1939 - present day.

18. Balance sheets and profit and loss accounts, 1889-present day. (Incomplete).

APPENDIX 5,3. Missing data in the cost and sales ledgers of Greenwood and Batley Ltd.

The total data set consisted of 4961 orders. Of these 4664 orders were for outside customers or for use by Greenwood and Batley itself. The remaining orders were for stock.

The following table shows the size of the complete data set, in terms of numbers of orders and of numbers of machines, for each of the major variables used in the analysis. Since these missing items are not exclusive, the exclusion from the data set of all orders for which at least one item of data was missing produced the cleaned data set of 2,435 orders which was used in most of the calculations in chapter 6 below.

Variable	No. of items where information given	
	Orders	Machines
No. of orders	4664	10662
Delivery date	4475	9915
Price	4240	10000
Date of work-start	3219	7522
Labour cost	3670	8203
Weight	3703	8324
Total Cost	4265	9622
Times of labour	3683	8208
Price and cost	3893	9018

CHAPTER 6

GREENWOOD AND BATLEY : PRODUCTION.

This chapter is concerned with the production by Greenwood and Batley of the machine tools whose sale has been described and analysed in the preceding pages. The production process in an industrial firm can be analysed in numerous ways, through study of the training and management of the labour force, the methods of management of the factory, the rate of building or other capital investment, or through other components of industrial behaviour. The records of Greenwood and Batley do not provide sufficient information to analyse these components separately. One measure, however, which serves to summarise the effects of all these other components, is that of changes in productivity, since the whole productive process, technical advance, and entrepreneurial behaviour contribute together to changes in the productivity of the factors of production.

The measurement of productivity is not only a useful method of summarising the behaviour of an individual firm, but it is also crucial to an understanding of the economic history of an industry, or of the country as a whole. Before presenting the results of an analysis of productivity change in the operations of Greenwood and Batley, it is therefore important to examine the possibility of generalising from the experience of this one firm to the experience of the engineering industry as a whole. If such generalisations can be based on the records of Greenwood and Batley, then it may be possible for these records to contribute towards the solution of the controversial topic of the course of the British industrial economy in the second half of the nineteenth century.

It is difficult to define a 'typical' firm, or to establish whether a firm is 'representative' of the industry of which it forms a part. Luckily, for most purposes it is not necessary to establish whether the firm which is to be studied is 'typical' or 'representative' in all respects; normally it is only necessary to know whether it is so in respect of the particular characteristics or facets of the industry which are to be explored. Thus if the subject of enquiry is the trend of wages in the engineering industry, and it is known that all engineering firms paid the same wages, then the experience of one firm would be a complete guide to the experience of the industry as a whole in this particular respect. That firm may be fifty times larger than any other firm, and totally atypical in all kinds of other ways, but in this particular case of wages it would be typical, and, for a study of wages, that is all that matters.

In most cases, however, the subject of enquiry covers characteristics of firms which cannot be expected to be uniform over all firms, such as size, location, products or age. In these cases, there is a spectrum of firms, from smallest to largest, from north to south, and so on. This is true of productivity change and its causes and results. It is likely that there are, in an industry, some firms whose labour productivity, for example, is very much higher than that of other firms; there will, in the common terminology, be a spectrum of firms ranging from 'best practice' to 'worst practice' firms, with respect to this particular characteristic, labour productivity. It would of course be possible to enquire where a particular firm falls along the spectrum, but it is normally very difficult to answer such a question in an historical

study, because of the scarcity of evidence on all but a few firms. It is thus normally impossible to say with any degree of confidence whether the experience of one firm at one period of time represents the best or the worst practice at that time, or where it falls on the spectrum. Normally, however, the interest lies not so much in the position of one firm, but in the trends observable in the industry as a whole over a period, for instance in the rise in the productivity of labour over the period. In this case, it would not be necessary to know where the particular firm from whom information is taken lies on the best-worst practice spectrum, but merely whether it maintains whatever position it has over the period. If, for example, a firm begins as technically most advanced, but by the end of the period is generally known as backward and conservative, by comparison with other firms, then naturally its experience does not provide a good base for the drawing of general conclusions about the industry. If, however, the firm is known to stay, throughout the period, at roughly the same point on the spectrum, then it may be possible to extrapolate from its experience to that of the industry as a whole.

It has already been argued, in the last chapter, that the technical standing of Greenwood and Batley in the machine tool industry was such as to place it among the 'best-practice' firms, and that in spite of its financial difficulties it remained advanced in technical terms at least until 1900. The most relevant characteristic for the purposes of this chapter is not however the standing of the products of the firm, but the relative standing of the methods by which the machine tools were produced. As the

comments of the American engineer, Porter, on the Whitworth works, demonstrate, it was quite possible for a high reputation among outsiders to coincide with deplorably backward methods of production.[1] There is however no evidence that Greenwood and Batley were, in their production of machine tools, anything other than the 'best-practice' plant which the praise of their products suggests. Descriptions of the works by outsiders were favourable, and it is clear from the order books of the firm that the most advanced machine tools were regularly applied to production, being transferred to the 'Untensils Account' of the firm, as well as being sold to outside customers. Although the financial structure of the firm, and the control of its commercial operations, were heavily criticised after 1890 both by several of the directors and by outside commentators, no criticisms of technical performance were made, and the impression created by these comments is that many of the commercial difficulties were the result of the technical progress and inventiveness of the firm outrunning demand and the ability of the salesmen to sell the machines. It is clear, therefore, that Greenwood and Batley were, throughout the period, among the 'best-practice' firms in the machine tool industry, both in terms of the products which they made and in terms of the methods which they used.

There is no evidence that Greenwood and Batley differed from other leading firms in the industry in its treatment of, or relations with, its labour force. The engineering industry was heavily and successfully unionised, and the rates of wages paid were common to all firms within a

1 See p.— above.
Porter, J.T. Reminiscences of Life as an Engineer
(MM & London 1908) pp. 115-124.

district, although there were minor variations between districts.[2] Greenwood and Batley appear from the Minutes of the Board of Directors, to have paid the wages normal in the engineering trades in Leeds, and they were allied with the other employers in the engineering strike or lock-out of 1897.[3] The firm was also typical in adhering to the practice, apparently normal in Leeds, of giving or taking no notice of leaving employment; a man could be employed, be dismissed, or leave of his own accord, at any meal-break, giving a highly flexible, if insecure, labour force.[4] The labour force of the firm was certainly large by the standards of most firms in the engineering industry, reflecting the range of products made, but there is no evidence that it was atypical in any other respect.[5] The family control of the firm, at least until 1888, and the division of responsibility between the partners, which has been described in the last chapter, also seems normal for a business at this time.

2 The Engineering Supplement to The Times gave wage rates for the Glasgow engineering industry in its issue of Feb. 20, 1907, and for Lancashire on June 12, 1907. Page, W, Commerce and Industry (London, 1919) gives on page 214 wage rates for London and Manchester from 1874-1914. The reasons for these differences were discussed by J. Stafford Ransome in a series of articles on 'Wages in the Engineering Trade' in Engineer, vol. 81, 3rd April, 8th May, and 5th June, 1896. The annual reports of the Factory Inspectors also give information on wage-rates.

3 Greenwood and Batley Ltd., Minutes of the Board of Directors, various dates in 1896 and 1897.

4 Greenwood and Batley Ltd., Minutes of the Board of Directors, 15th March, 1892.

5 See p. 364 below.

In two respects the firm was certainly atypical. It made, firstly, many more types of engineering goods than was normal.. In its organisation, however, the production of each type was segregated, so that it does not appear likely that the scale of the firm as a whole altered the conditions under which a particular product was manufactured; machine tool production was quite separate from the rest of the firm. The firm was secondly atypical in the closeness of its relationship with the government arms factories, a closeness which stemmed from the early work of Thomas Greenwood in designing and producing tools for these factories. As has been demonstrated, this connection was valuable for the firm in the larger profits which it made on arms orders, for the British and foreign governments. In this context, however, of change in methods of production it seems likely that the connection was valuable in giving Greenwood and Batley access to new ideas and designs developed by the government engineers, and it is possible that this gave it an advantage over other firms. It does not seem likely, however, that such advantage could be very great, since any new ideas and designs were apparently quickly publicised in the trade press, and could be taken up at will by other firms.

Greenwood and Batley seem, therefore, to have ranked among the 'best-practice' machine tool firms as far as technical advance and the quality of their products are concerned; in other respects, with the possible exception of their size and the number of products which they made, they do not seem to have been atypical in comparison with the leading firms in the industry. They are clearly unlike

the smaller and less technically progressive firms in the industry, who formed the tail behind the 'best-practice' firms. Nor are they representative of the specialised firms making machine tools for such customers as the ship-building industry. Nevertheless, it is clear that Greenwood and Batley were consistently among the leaders of the industry in their working methods and in the quality of their products; in these circumstances, it is reasonable to regard the changes in productivity of the factors of production which are observable in their records as roughly representative of trends in 'best-practice' machine tool practice at this time. At the least, the Greenwood and Batley data on productivity change demonstrates what it was possible for one firm to achieve; at the most, if it can be regarded as representative, it can provide some information on the nature and causes of productivity change in British engineering as a whole.

The Accounting Methods of the Firm and their Relevance to the Study of Production.

The sources for the study of the production of machine tools in this chapter are the records of the firm of Greenwood and Batley, and in particular their cost accounting and order books. As Greenwood and Batley made many products besides machine tools, it is impossible in this study to use the aggregate financial records of the firm, where these exist, in any systematic manner; such aggregate records can do no more than give an impression of the progress of the company, and they have been used in this way in the last chapter. Specifically, although the aggregate records give information on the additions to the plant and machinery of the firm which were made during the period, it is

impossible to attribute the new machinery which was bought or manufactured to one or other of the lines of production of the firm. It is therefore impossible to calculate, or to obtain from the aggregate records, the capital cost of the machinery or buildings used by Greenwood and Batley to construct their machine tools; it is further impossible, since there is no information about the technical performance age, or type of machines being used, to establish any technical production functions, the technical relationships between the input of raw materials and the output of finished machine tools or their component parts.

Secondly, the accounting methods used by the firm make the information provided by the cost books of limited value in exactly the same field, the estimation of the capital inputs. The method adopted by Greenwood and Batley in calculating total costs of production on each order was extremely simple. From records of the number of hours worked by each of the five types of labour employed, the direct labour cost of the order was easily calculated. The metal cost of an order was also directly calculated from a list of the metal inputs used. There remained the problem of calculating the overhead costs, office and sales expenses and other miscellaneous costs, and the capital costs of the machinery employed. To cover these costs Greenwood and Batley adopted the simple method of taking the direct labour cost and adding the same sum into the cost calculations, under the name of 'management cost'; in the accounts of the firm, therefore, with very rare and unimportant exceptions, 'management costs' exactly equalled direct labour costs on each order.

Greenwood and Batley were not alone among contemporary

engineering firms in using this method. The whole question of the calculation of management costs was carefully considered by the Morley Committee on the Manufacturing Departments of the Army, apparently because of allegations from private manufacturers that the lower costs of manufacturing recorded by the government factories reflected not greater efficiency but rather a different method of calculating overhead costs.

The Morley Committee were told by the Accountant and Auditor to the government factories that :

> "I do not know what practice prevails at present in large manufacturing Establishments of private firms, but in forming an estimate of prices I have been told by several that they take the material and the labour and then add 50%."

In the government factories, however, the practice was to charge indirect expenditure as a percentage of the direct labour cost alone :

> "The total indirect expenditure is levied as a percentage upon the direct labour charged against each order in the cost ledger of each department. The amount of indirect expenditure is constantly varying according to the amount of work which is being turned out. Last year it amounted to about 48% on direct wages."[6]

This charge was however not intended to cover depreciation or capital expenditure on machinery. After hearing other evidence, the Committee concluded in its report that "In private factories it appears that there is no uniformity in the manner of charging machinery."[7]

6 Morley Committee. Report of the Committee on the Organisation and Administration of the Manufacturing Departments of the Army. (P.P. 1887, xiv 1), Q.5429.

7. Morley Committee, op.cit., Report, paragraph 101.

Accounting manuals of the period gave guidance on the accounting practises which should be adopted, while recognising that the advice was not often followed. A work on "The Management of Small Engineering Workshops", for instance, which was published in 1899, stated that the theory of estimating 'costs of establishment' was that :

establishment cost = wages paid on order multiplied by $\frac{\text{total yearly est. cost}}{\text{total yearly wages.}}$

In practice, however, the method adopted was to :

> "add a percentage of the estimated wages cost, which percentage is calculated from the experience of previous years, and it is only an estimate for the current year in a very rough sense."8

Greenwood and Batley were thus not in any way exceptional in their methods of accounting. The firm does not seem to have realised that, as the Morley Committee pointed out, :

> "As this expenditure is distributed among all the articles produced in proportion to the cost of direct labour expended upon them, it follows that articles which are produced chiefly by manual labour and comparatively cheap machines are charged too highly, while, conversely, articles which require for their construction complicated and expensive machinery, directed by few hands, are charged too little."9

The directors of Greenwood and Batley seem in fact to have discussed the system on only two occasions. In 1891 Mr. Wurtsburg, while discussing the valuation of stocks in hand, explained the system used :

8 Barker, Arthur H. The Management of Small Engineering Workshops (London and Manchester, 1899), p.187.

9 Morley Committee, op.cit., Report, paragraph 101.

> "In working out actual costs the Managing Directors always added 100% for expenses and charges, on to the actual cost of labour; so that there was ample margin between the 60% charged on stock and the 100% when the orders came to be weighed up; and therefore the stock was taken at a low and safe rate. He further explained the system of taking quarterly balances and of ascertaining the actual rate of Expenses and Wages, the results showing that in busy times the rate of expense went sometimes as low as 75%, whereas in the quarter April to June last it had been 98% and in the quarter July to September 82%."[10]

The Board showed no wish at that time to alter the system, but when it was again discussed, in 1913, they were told that an allowance of 100% on direct wages was no longer enough, and that an increase would have to be considered.[11]

However normal the system was for engineering firms in the late nineteenth century, it has severe disadvantages from the point of view of an historical analysis of the production of engineering goods. As has been mentioned in the last chapter, it is impossible to assess the true profit rate on any individual order, since on the evidence of Mr. Wurtzburg's statement the 'management cost' figure could conceal a hidden profit of up to 27% of direct labour costs, depending upon the utilisation of capacity. While this difficulty does not affect significantly the validity of the estimates of relative profit levels on orders to different types of customers, described in the last chapter, it makes it impossible to construct estimates of the capital cost of any order for use in analysis of the productive process. Although it is possible to construct an index of capacity based on the number of hours worked within a month, the use of such an index to deflate the 'management cost'

10 Greenwood and Batley Ltd., Minutes of the Board of Directors, Nov. 30, 1891.

11 Greenwood and Batley Ltd., Minutes of the Board of Directors, Jan. 29, 1913.

figure to arrive at a better approximation of capital cost is not sensible; such an index of capacity would assume constant labour productivity, which is too restrictive an assumption. Another difficulty with such a procedure is that even the deflated 'management cost' figure is too highly correlated with the direct labour cost to permit of the use of Cobb-Douglas production function analysis. The accounting procedures of Greenwood and Batley thus rule out any approach to the analysis of the production process through the use of the classical production function.

The accounting methods also have a more general defect, in that for a number of orders data is missing from the cost ledgers on one or other aspect of production, perhaps the weight, or the time taken in production of the order. In the whole of the statistical study of productivity movements, therefore, the results are based upon calculations on a set of data from which all orders with missing information have been removed. Approximately 50% of orders had some data missing, the principal reason for such omission being that the order was for stock of for the use of Greenwood and Batley itself; in these cases the delivery date of the machine, or its price, respectively, were normall omitted. This procedure is regrettable in that data is being wasted, but the remaining sample size (over 2,000 orders for 5,551 machine tools) is so large that it is unlikely that any serious distortion has resulted. An alternative procedure, the insertion of values for the missing data based on the values which can be found, is subject to serious objections which have already been discussed.

Productivity change in the operations of Greenwood and Batley

The problems of the measurement and description of productivity change are very great, and they are particularly intransigent in an industry such as that making machine tools, in which the products manufactured are heteregeneous. The comment of a contemporary observer that Greenwood and Batley's products were, in the early years of this century, 'multifarious', has already been mentioned,[12] and in the field of machine tools the firm made, during the period 1856 to 1900, 793 differently-named metal working machine tools, of which 457 were ordered only once during the period. To call these machine tools different types is perhaps to overstate heterogeneity, since many were of course only slightly modified versions of a mass-produced, or at least often produced, machine tool, but these two figures illustrate the lack of standardisation in the product called a 'machine tool'. The lack of standardisation presents the problem of whether it is possible to discover a unit of output which is sufficiently invariant to be used as a yardstick in productivity measurement.

The Greenwood and Batley records suggest two possible units. The number of machine tools made is known, and so is the net weight of each machine tool produced. It is therefore possible, arithmetically, to use either the number of tools, or hundredweights of machine tools, as units in productivity measurement. The important question is whether it is justifiable to do so theoretically, or whether quality changes in the product make the units, of either type, so variable over a 45 year span, that no comparison is possible between machine tools built in 1856 and those built in 1900. If this is so, then measurement of productivity change is meaningless.

12 See p.39 above.

To consider first the use of machines as the unit of measurement; it is clear that Greenwood and Batley manufactured many different kinds of machine tools, ranging from amateur turning lathes to the giant engine lathe which they exhibited at Paris in 1889. To attempt to regard these two extremes of machinery building as 'machine tools', and to calculate unit costs, or units produced per man-hour, would seem ludicrous. On the other hand, these were extremes, which stand out in the records because they are out of the ordinary. The majority of the tools which Greenwood and Batley built, which form the major part of the data for an aggregate study of productivity, were medium sized tools, weighing perhaps a ton, and costing about £100 or less. Although there is a tendency for machines to get heavier, and more expensive, over the period, the fact that most machine tools made by the firm fall into this medium price, medium weight category makes it more justifiable to utilise machines as the unit for productivity analysis. In doing so, however, it is necessary to take account of another source of error, which applies also to calculations based on weight, in which the unit itself (a hundredweight of metal), obviously does not vary as one machine does from another, although the type of metal used may change. The difficulty which arises with both weight-based and machine-based units is that of quality changes over time.

It is inevitable that, in a period of rapid technological change such as that being considered, the purposes, methods of work, capabilities, physical characteristics and appearance of a machine vary without the name of the machine changing. A lathe of 1856 was a very different machine in many of these respects from a lathe of 1900.

The difficulty therefore is whether such changes vitiate any comparison of productivity in manufacture over time, since the unit of output is not the same at the end of the period as it was at the beginning. This difficulty, common in productivity measurement, is made more complicated in the case of the machine tool industry because the output, a machine tool, is the same thing as one of the major inputs, the machine tool on which it is made. Any explanation of productivity change which is based on some form of technical change in the machine tools used to make machine tools therefore implies that the machine tool being made is changing at, roughly, the same rate of technical change. The vital question is therefore whether it is at all possible to explain or even describe productivity changes in the machine tool industry, without making the totally unrealistic assumption that there was no technical change in the industry.

It can be argued that this difficulty is more apparent than real, in that the difficulty is caused by a verbal rather than a real confusion. If one considers the machine tool that is being made as a series of blocks of metal being machined and fitted together, and the machine tool that is being used in this process as a machine that is being used to machine metal, then it is possible to distinguish between machine tools as inputs and machine tools as outputs. If this can be admitted, then the difficulty of productivity measurement in the machine tool industry becomes one of discovering whether the machine tool (as a block of machined metal) was significantly changed over the period, even though its capabilities (as a machine for machining metal) obviously were.

There is considerable reason for arguing that such a distinction can usefully be made. Many of the innovations in machine tool design during the late nineteenth century were of a very minor character in terms of changes in the physical appearance of the machine, although they gradually improved its efficiency and ease of operation. Woodbury described the evolution of an early grinding machine :

> "His (Joseph R. Brown's) first grinding machines were designed for dry grinding the needle bars, foot bars and shafts of the Willcox and Gibbs sewing machine. The basic principle of these first grinding machines was to modify a 14-inch Putnam lathe for the purpose, by adding an emery wheel on the carriage, and attaching a longitudinal feed mechanism and reverse. Drawings showing the method of constructing these attachments are in the possession of Brown and Sharpe, dated respectively November 26, 1864 and November 25, 1864. A dead center pulley, an important element in obtaining precision grinding, is shown in a drawing also of 1864, but it is clear that cylindrical grinding had been done before this, for there is also a drawing of September 22, 1862, for a solid back rest. Later a spring-back rest consisting of a series of leather washers carried on a spring rod was used. Skill in adjusting these back rests was required to prevent chattering. In these early days wet grinding was done by holding a wet sponge against the work. Later a supply of water was provided through a nozzle, as shown in a drawing of December 22, 1866. By 1867 a guard was placed on the ways of the lathe to keep off the water and the emery."[1]

This passage refers to the very early history of the grinding machine, but this process of small-scale improvement could also apply to much more highly developed machine tools. Woodbury in another monograph, that on milling machines, discusses the evolution of methods of adjusting the table on which the workpiece was placed :

13 Woodbury, R.S. History of the Grinding Machine (Cambridge, Mass., 1959), pp.61-2.

"In 1881-2 the Cincinatti Milling Machine Company first introduced the placing of crank or hand wheels at an angle so as to clear each other. This machine was also the first centralised control milling machine. By having the spindle rotating anti-clockwise this miller could use standard drills, boring tools, reamers etc. designed for drill presses and lathes. This naturally required placing the indexing head on the right hand side of the table. The operator thus logically stood on the left hand side of the knee where he could conveniently operate from one point the table controls, the knee controls, and the lever to the countershaft belt. With their swivel vise and the Holz and Mueller dividing head this machine was especially convenient for high accuracy in gear cutting. In 1899 O.J. Beale invented a hand quick-return movement which preserved the directional revolution by direct internal gearing. Quick or slow traverse of the table by the same hand wheel was patented by J. Edgar of Becker-Brainard Milling Machine Company, but seldom used after power quick return was generally adopted. Provision for the hand wheel to stand still while power traverse is operating was made in Brown and Sharpe machines in 1911-1912."[14]

Such examples could be multiplied, but their significance is clear, that the basic machine did not change markedly, but that detailed changes could add very greatly to convenience and speed of operation, and to the capabilities of the machine tool. The fact that the basic machine tool need not change very greatly can be illustrated by three comments from Woodbury's monographs, that the Brown and Sharpe Universal Milling Machine of 1861 "embodies nearly all the basic features of milling machines to this day", that the same firm's Universal grinding machine of 1876 "introduced the basic form which the cylindrical grinding machine was to have in future", and that "production-type gear cutting machines embodying all the basic methods of forming the

14 Woodbury, R.S. History of the Milling Machine (Cambridge, Mass., 1960), pp.78-9.

"teeth had been developed by 1850".[15]

The major changes in the field of machine tools were therefore the introduction of new types of machine tools, rather than the modification of existing types. It can be seen in the records of Greenwood and Batley that very few completely new machine tools were introduced into the output of the firm, and those that were such as milling and grinding machines were manufactured from very early in the history of the firm, principally because of the willingness of Thomas Greenwood to adopt the new American ideas. For most of the period, therefore, the changes in the machine tools manufactured by the firm appear to have been of the minor rather than the major type.

If this distinction can be admitted, the next step in the argument is to decide how much difference was made to the manufacture of a machine tool by the introduction of a minor change in its design. Unfortunately, in the absence of detailed engineering data, the answer to this question is difficult to discover. It can however be argued that the probability is that it did not make a great deal of difference. The introduction of a new tool, for instance, to the turret head on a capstan lathe would almost certainly make only a minute difference to the speed or ease of manufacture of that lathe, and the same would apply to the improvements listed in the quotations from Woodbury.

15 Woodbury, R.S. History of the Milling Machine (Cambridge, Mass., 1960), p.44. History of the Grinding Machine (Cambridge, Mass., 1959), p.58, and History of the Gear-Cutting Machine (Cambridge, Mass., 1958), p.77.

If both these propositions, of the minor nature of design changes, and of the minor effect of these on the manufacture of the changed machines, can be accepted, then it can be argued that it is possible for very considerable technical change in the machine tool as a machine for machining metal to exist side by side with very little chang in the machine tool as an assemblage of pieces of machined metal. If this was so, then it should be possible to measur productivity change in the production of machine tools, and to adduce technical change as one possible explanation of such change. It may, on the other hand, be argued that, even though one design change is of minor significance, the totality of such changesiover a 45 year period would be of significance, and that long-period comparisons are thereby invalid. This is possible, but many of the machine tools made by Greenwood and Batley seem, at least by their descrip ions and photographs, however superficial such a test is, to have remained very much the same throughout the period. Since this, and the foregoing propositions, are at least plausible, if unproven, it seems worthwhile to attempt to make some measurements of productivity change, however rough these may prove to be. Further justification for such an attempt can be found in the likelihood, to put it at its lowest, that any technical change during the period was positive, that is that there was no loss in technical knowledge. If this is so, then to assume in the productivit calculations that machine tools were the same in 1900 as they were in 1856 is to err on the side of caution, and will understate the change in the machine tool (as a machine to machine metal). In other words, if the capability of the machine tool being made is taken into account, as well as its existence as an inert block of metal being machined

we will have understated the degree of productivity change, since a given number of units of input may produce, at the end of the period, a more valuable unit of output, as well as producing it more quickly.

Since many of the statistical series which result from the Greenwood and Batley records are expressed in price terms a further problem in using the data is that of transforming it into real price terms. This raises two problems, the series of price indices which are to be used to deflate the series derived from Greenwood and Batley, and the selection of a base year for the transformations. The Greenwood and Batley data give, in price terms, data on raw material inputs, manufactured machinery output, labour costs, and wages; ideally different price indices should be used to deflate each of these Greenwood and Batley series. There is however no acceptable price series for manufactured machinery, and the price indices of metal usually refer to pig-iron, which was only one of the materials used. Engineering wage data are available, but only for the skilled workers who made up only a part of the Greenwood and Batley labour force. In view of these difficulties, and because of the relative computational simplicity of this course, it was decided to use a general price index, the Sauerbeck-Statist price series, which is an amalgam of feed and raw material prices, and seemed the least unsuitable index for the purpose. The major alternative, the Rousseaux price indices, are more comprehensive in their coverage of imports foodstuffs and raw materials, but the additional series used are not relevant to Greenwood and Batley, and so do not provide a reason for using the Rousseaux rather than the Sauerbeck-Statist index. In addition the two series move

broadly together for this period, so that the choice of one of the other is not of great significance. The selection of the date to use as a base for the transformations has, as usual, to be made on rather arbitrary criteria; it seemed computationally easier to use a date near to the beginning of the period. 1859 was the first year in which Greenwood and Batley seem to have settled down to receiving a steady flow of orders, and since this was an important consideration in the production of meaningful statistics of volume of production, this year was chosen, again for computational convenience, as the base year for the transformations using a price index. Some series were themselves further transformed into indices, principally those, like the statistics on weight or number of machines produced per hour worked, in which the absolute numbers as a result of division were very small. This does not affect the validity of correlation coefficients calculated from the data, but since transformation to index number form does affect regression estimates, untransformed data were used wherever regression estimates were required; the results given below are based on the series transformed to index number form unless otherwise stated.

In view of the importance of the study of productivity changes to the history of the British machine tool industry during the period, it seems feasible to discount the effect on the estimates of the possible sources of error which have been mentioned, and to make a study of productivity within Greenwood and Batley. Because of the possible sources of error, both weight-based and number-based units will be used in the analysis, and an attempt will be made to explain and resolve the differences between them.

As a first step in the analysis of the production record of Greenwood and Batley, yearly values were calculated for a number of major variables, and linear time trends calculated from these. The analysis was concentrated on the variables most relevant to productivity change, that is to various measures of output relative to the factor inputs. In the absence of a measure of capital cost, the 'margin cost' (total cost minus direct labour cost minus raw material cost) was used as a substitute.[16] The linear trend over a 45 year period (1856 to 1900) may conceal considerable variation around the trend, and in this case even with the large sample size some abnormal orders appear to have distorted the patter to some extent in a few years. It can be seen from the plots of some of the variables which are given in graphs 6, 1 to 4, however, that the linear trends calculated do not seriousl distort the underlying movements of the variables.

Table 6, 1 presents the results of the calculations of the linear trends. Calculation of growth rates on the basis of the linear trends shows that cwts. of metal produced per man hour rose by 2.4% per annum if total man-hours are used in the calculation, or by 2.3% per annum if the hours of labour are weighted by the wage-rates of the different categories of labour employed. Over the whole period, this growth was sufficient to raise production per man-hour from 0.0097 cwts. per man-hour to 0.027 cwts per man-hour, (or from 0.043 cwts per man-hour to 0.118 cwts per man-hour if the weighted labour total is used.) In other words, labour productivity appears to have approximately trebled in the 45 years between 1856 and 1900, a sizeable and significant increase.

16 See p. 356-30 above, and, for a full discussion of this variabl p. below.

Value added per cwt.	$y_t = 3.57 + 0.001x_t$	S.E. of b = 1.21
Price per machine	$y_t = 47.49 + 3.27\ x_t$	S.E. of b = 1.63
Value added per machine	$y_t = 15.45 + 4.63\ x_t$	S.E. of b = 33.30
Weight per machine	$y_t = 5.23 + 1.47\ x_t$	S.E. of b = 21.36
Cwt. per hour A	$y_t = 0.0097 + 0.[illegible]x_t$	S.E. of b = 0.006
Cwt. per hour B	$y_t = 0.0431 + 0.0017x_t$	S.E. of b = 0.271
Machines per hour A	$y_t = 0.00001 - 0.00001x_t$	S.E. of b = 0.00028
Machines per hour B	$y_t = 0.00369 - 0.00004x_t$	S.E. of b = 0.00113
Labour cost per machine	$y_t = 5.622 + 2.005x_t$	S.E. of b = 27.512
Labour cost per cwt.	$y_t = 1.479 + 0.002x_t$	S.E. of b = 0.405
Metal cost per cwt.	$y_t = 0.591 + 0.001x_t$	S.E. of b = 0.196
Metal cost per machine	$y_t = 2.256 + 1.064x_t$	S.E. of b = 19.27
Margin cost per machine	$y_t = 7.362 + 0.[illegible]x_t$	S.E. of b = 23.66
Margin cost per cwt.	$y_t = 2.036 - 0.0075x_t$	S.E. of b = 0.397
Price per cwt.	$y_t = 4.317 - 0.042x_t$	S.E. of b = 1.274

TABLE 6, 1. Linear trends in variables relevant to productivity change, Greenwood and Ratley, 1956–1960.

GRAPH 6.1

WEIGHT PER HOUR WORKED, EXPRESSED AS INDEX (TOTAL HOURS) (TO BASE 1859 = 100)

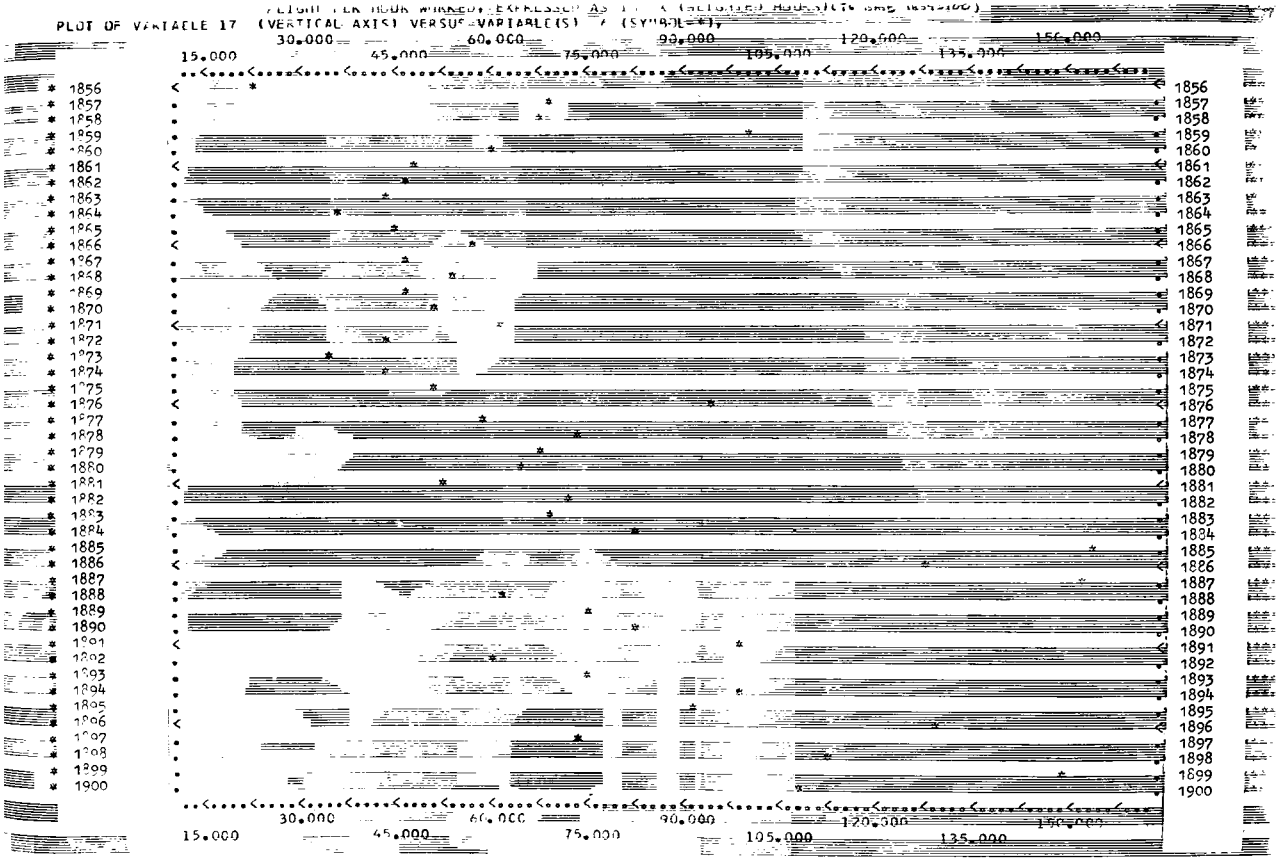
PLOT OF VARIABLE 17 (VERTICAL AXIS) VERSUS VARIABLE(S) 5 (SYMBOL=*),

15.000 30.000 45.000 60.000 75.000 90.000 105.000 120.000 135.000 150.000

1856 1857 1858 1859 1860 1861 1862 1863 1864 1865 1866 1867 1868 1869 1870 1871 1872 1873 1874 1875 1876 1877 1878 1879 1880 1881 1882 1883 1884 1885 1886 1887 1888 1889 1890 1891 1892 1893 1894 1895 1896 1897 1898 1899 1900

15.000 30.000 45.000 60.000 75.000 90.000 105.000 120.000 135.000 150.000

5/5 GRAPH 6,2


PLOT OF VARIABLE 17 (VERTICAL AXIS) VERSUS VARIABLE(S) 7 (SYMBOL=*),
15.000
30.000
45.000
60.000
75.000
90.000
105.000
120.000
135.000
150.000
1856
1857
1858
1859
1860
1861
1862
1863
1864
1865
1866
1867
1868
1869
1870
1871
1872
1873
1874
1875
1876
1877
1878
1879
1880
1881
1882
1883
1884
1885
1886
1887
1888
1889
1890
1891
1892
1893
1894
1895
1896
1897
1898
1899
1900

BMDP3D GENERAL PLOT--INCLUDING HISTOGRAM - REVISED JANUARY 27, 1969
HEALTH SCIENCES COMPUTING FACILITY, UCLA

GRAPH 4.3

NUMBER OF MACHINES PER HOUR WORKED AS INDEX, (TOTAL HOURS)(1960 = 100)

PLOT OF VARIABLE 17 = (VERTICAL AXIS) VERSUS VARIABLE(S) 18 (SYMBOL = A).

80.000 160.000 240.000 320.000 399.999

40.000 120.000 200.000 280.000 350.000

1856
1857
1858
1859
1860
1861
1862
1863
1864
1865
1866
1867
1868
1869
1870
1871
1872
1873
1874
1875
1876
1877
1878
1879
1880
1881
1882
1883
1884
1885
1886
1887
1888
1889
1890
1891
1892
1893
1894
1895
1896
1897
1898
1899
1900

40.000 120.000 160.000 200.000 240.000 280.000 320.000 350.000 399.999

BMD05D GENERAL PLOT - 1 OUTPUT HISTORY - REVISED JANUARY 27, 1969
HEALTH SCIENCES COMPUTING FACILITY, UCLA

GRAPH 6.4

NUMBER OF MACHINES PER MAN-HOUR WORKED AS INDEX, (WEIGHTED HOURS)(TO BASE 1954=100)

PLOT OF VARIABLE 17 (VERTICAL AXIS) VERSUS VARIABLE(S) 11 (SYMBOL=*),

80.000 160.000 240.000 320.000 400.000

40.000 120.000 200.000 280.000 360.000

1856
1857
1858
1859
1860
1861
1862
1863
1864
1865
1866
1867
1868
1869
1870
1871
1872
1873
1874
1875
1876
1877
1878
1879
1880
1881
1882
1883
1884
1885
1886
1887
1888
1889
1890
1891
1892
1893
1894
1895
1896
1897
1898
1899
1900

80.000 160.000 240.000 320.000 400.000

40.000 120.000 200.000 280.000 360.000

On the other hand, table 6, 1 also shows that production of machines per man-hour fell during the period. Again calculating the growth rates, that for machines produced per man-hour using total hours is -1.8% per annum, or for the weighted labour -1.5% per annum. This was equivalent to a cut of one-half in the productivity of labour over the 45 year period. Since the denominator (man-hours) in the calculations of production per man-hour is the same in each case, produced per man-hour and cwts. of machines produced per man-hour, it is clear that the explanation for this apparent discrepancy between trends must lie in a changing relationship between the numbrators, number of machines and weight of machines; in other words the explanation must be that the average weight of machine tools was rising. As table 6, 1 shows independently this was in fact the case. Calculation of the growth rate in the linear trend of weight per machine shows that average weight was growing by 6.1% per annum in the 45 year period. (This figure is to some extent distorted by a very large jump in average weight per machine in 1898 and 1899; exclusion of the years 1856-8 and 1898-1900 however still shows a growth rate over the 39 year period of 5.0% per annum.)

Variations in the average weight of machines are not however entirely responsible for the fluctuations in productivity expressed as numbers of machines produced per man-hour. A regression of machines produced per hour on cwts. produced per hour and average weight per machine gives an R^2 (coefficient of determination) of 0.3017, indicating that the combined variance of these two last variables was responsible for only approximately 30% of the variance in number of machines produced per man-hour; this proportion is so low as not to be very significant, either statistically or

theoretically. However, the fact that the variance in machines produced per hour was not the product of these two other variables does not detract from the common-sense observation that the fall in productivity expressed in these terms, over the whole period, must have been affected by the two contrary movements, that the average weight of each machine was increasing, but that each cwt. of machinery was taking less labour in terms of man-hours to produce.

The increase in production of cwts. per man-hour, and the residual fall in production in machines per man-hour (when the effects of average weight and more weight produced per man-hour are removed) can perhaps be explained by the same factor, which stems from the fact that machine tools are unique in that, for a machine tool maker, a machine tool is both an input and an output. In other words, machine tools were, gradually, becoming more versatile and more efficient, but they were also becoming more complicated; they therefore took longer to make, although they themselves allowed the metal of which they were made to be machined more quickly and more easily. The explanation for the change in productivity which have just been observed may therefore be the effect of technical change, operating in this unique industry on inputs and outputs simultaneously.

This explanation is attractive, but it needs closer examination, since it is too easy to ascribe productivity changes to technical changes and to go no further. It is therefore necessary to explore how technical changes could have affected productivity in machine tool manufacture,

to check whether other related evidence is consistent with this explanation, and finally to seek other explanations which might be consistent with the evidence.

'Technical change' is a term which covers two processes, firstly substitution between the factors of production, that is shifts within the production function, and secondly changes to a new production function, "superior to its predecessor in the sense that less of one or more factors of production is required to produce a given output, the input of other factors remaining unchanged."[17] At any one time, or over a longer period, both these types of change may be occurring, dependent upon changes in the costs of the factors of production and upon changes in technical knowledge; furthermore, as Salter points out, it is often impossible to distinguish between these two influences or between the effects which they produce. It is apparent that in the production of machine tools there must have been scope, over such a long period as 45 years, for factor costs to alter considerably, and technical knowledge in the field of machine tools was also greatly augmented over the period. For these reasons, assessment of which influence was paramount over the period, and of how each influence affected the production of machine tools, is extremely difficult. It is clear from the size of the changes in labour productivity, however, that the changes were considerable, and it is important to discover why they occurred. If the productivity change is attributable wholly to changing factor costs, then the inventiveness of the machine tool industry, in the sense of inventing machine tools which save all factors of production, is called into question, and explanations of British export decline in terms of entrepreneurial and

17 Salter, W.E.G. Productivity and Technical Change (Second edition, edited by W.B. Reddaway, Cambridge, 1969), p.21. Many of the methods and theories used in this study are derived from Salter's study.

technical decline become more plausible. If, on the other hand, the productivity change can be shown to have been the result wholly of 'true' technical change, or shifts to a new production function, then it is more plausible to attempt to seek for the causes of British backwardness in machine tools among demand or market conditions, since the increase in the productivity of labour, at 2.5% approximately per annum, is so considerable.

The major difficulty in assessing the causes of the increase in labour productivity which have been described lies in the character of the cost ledgers of Greenwood and Batley, which were designed not to answer such questions, but purely as day-to-day cost accounts. It has already been explained that the lack of any capital input measure makes it impossible to approach labour productivity through estimation of the production function at different periods. Similarly, the lack of a capital input measure, and thus of a capital cost figure, inhibits any attempt to measure changes in factor costs. Although labour and material cost figures are available, without capital cost figures no judgments on factor substitution would appear possible. There is however some data in the records of Greenwood and Batley which can be used to throw light on the question of whether factor substitution was responsible for the changes in the productivity of labour. The data is of two types, firstly evidence on factor shares in final price, and secondly evidence on the remuneration and utilisation of labour.

The relevance of the measurement of factor shares

to the possibility of factor substitution is that, if factor substitution on a substantial scale had taken place, then this substitution should have been reflected in factor shares in the final price of the product. If, for instance, the rise in labour productivity had been achieved by the replacement of men by machinery, then it is likely that the share of labour in the final price of the product would have been reduced, and the share of capital correspondingly increased. The correspondence cannot be expected to have been veryexact in practice, but there is no reason to think that there were any mechanisms at work in the period which would seriously distort the relationship. The engineering industry was a skilled, unionised industry, and at least until the engineering strike of 1896 the Amalgamated Society of Engineers and its fellow craft unions was said by its detractors to have been very successful in restricting employment and enforcing the 'rate for the job'. It is thus unlikely that any factor substitution which involved increased use of labour, or pressure on labour to work harder, would not have been reflected sooner or later in an increased share of labour in final price. On the other side, there seems to be no reason to believe that engineering entrepreneurs would be inefficient in securing an adequate reward for capital.

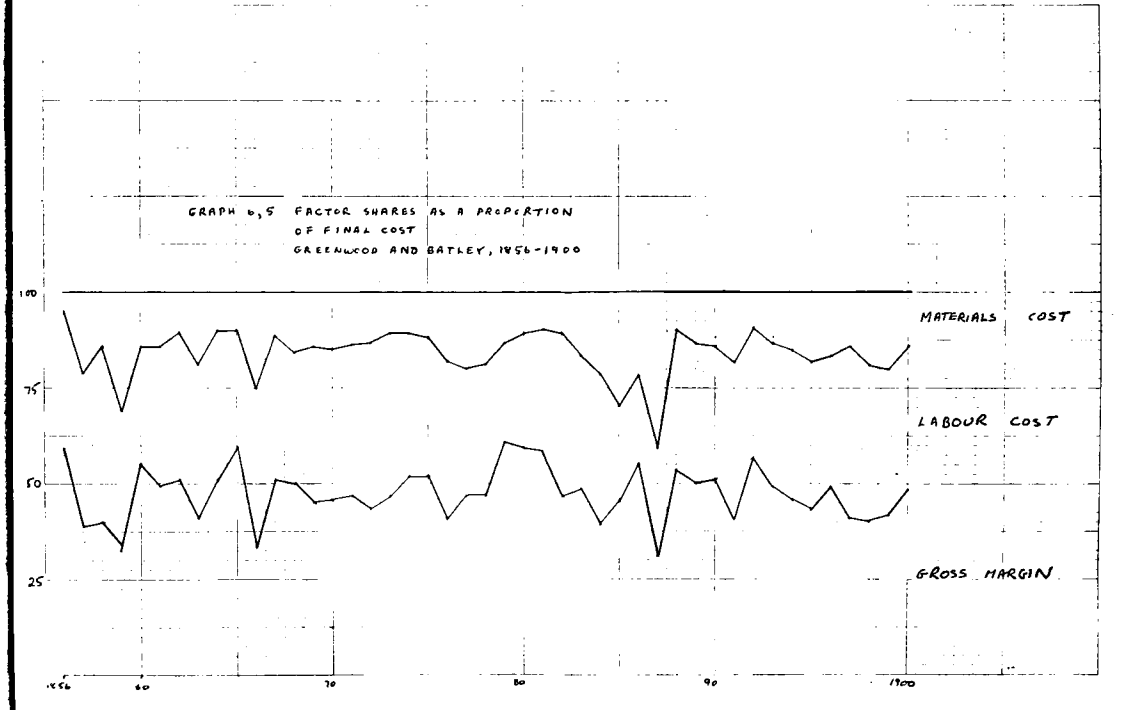
It is plausible, therefore, to use factor shares to throw light on the possibility of factor substitution. A major difficulty is that of assessing the share of capital, since, as has already been said, the 'management cost' figure in the Greenwood and Batley accounts includes an element of profit, depending on the utilisation of capacity, and also includes allowances presumably for depreciation

and the cost of machinery inputs. Since it is impossible to calculate the share of capital exactly, it is necessary to adopt the measure suggested by Salter in "Productivity and Technical Change", and to calculate labour cost, materials cost, and, as the third factor, 'unit margin cost' as a residual. In this case, therefore, labour cost is calculated as direct labour cost per unit of output, materials cost as materials cost per unit of output, and unit margin cost is obtained by subtracting labour and materials cost from total price per unit. Unit margin cost therefore includes profits, both open and concealed within 'management cost', office expenses, and other indirect costs. This procedure is open to many objections, and it is necessarily imprecise, but given the quality of the data it seems inevitable.

Factor shares as a proportion of final price, calculated on the basis described in the last paragraph, are shown for each year between 1856 to 1900, in graph 6, 5. It can be seen that factor shares were in fact very stable over the whole period, although there were naturally year to year fluctuations around the trend. The mean shares over the whole period are :

Labour	36.4%
Materials	16.1%
Margin (Residual)	47.4%

and the coefficients of variability (standard deviation as a percentage of the mean) are respectively 14.3%, 39.1%, and 14.8%, indicating a reasonably low degree of variation around the mean. The measure of unit margin costs is, as has already been stated, subject to all kinds of criticisms; if it is imagined that an increasing amount of indirect labour, or an increasing amount of capital inputs, as the


GRAPH 6,5 FACTOR SHARES AS A PROPORTION OF FINAL COST GREENWOOD AND BATLEY, 1856-1900
100
75
50
25
MATERIALS COST
LABOUR COST
GROSS MARGIN
1856
60
70
80
90
1900

expense of indirect labour, are included within it, then it is possible that the true shares of labour and capital were changing markedly, and were markedly different from those shown in graph 6, 5. Furthermore, in so far as the final price was determined by Greenwood and Bailey, rather than by competitive market forces, and it has been argued in previous chapters that machine tool producers had considerable freedom in pricing, then the method by which the firm calculated its past profit or loss might affect directly its future estimates for the price of tools. Since past profit or loss was calculated on the basis of equating management cost with direct labour cost, if prices were calculated on this basis then there would be an inherent stability in factor shares. For both these reasons, therefore, the calculations of factor shares, and their relevance to the existence of factor substitution, must be treated with caution.

Even if the evidence of stable factor shares is admitted, a major obstacle to concluding that that stability demonstrates the absence of significant factor substitution is the evidence produced by Salter on the effects of factor substitution upon factor shares. He concludes his discussion of this subject with the words :

> "... relative shares are remarkably insensitive to factor substitution. ... The economic reason for this insensitivity is, of course, that changes in shares are the result of two factors pulling in opposite directions; the relative cheapening of one factor, and the tendency to use more of this factor. Consequently, large changes in relative factor prices, or large differences in the strength of the opposing forces (as measured by the elasticity of substitution) are necessary to induce moderate changes in shares. Moreover, these... calculations refer only to two factors; where there are more than two factors the change in relative shares is likely to be even less."[18]

18 Salter, W.E.G., op.cit. pp.136-7.

Although it is possible to hazard that the elasticity of substitution of capital for labour in the machine tool industry at this period was probably low, in that the manufacture of machine tools was still regarded as a craft industry, and it was generally necessary for all fine work to be carried out by hand, because of the inaccuracy of the machine tools, very little reliance can be placed on this suggestion. In view of this, of the difficulties of the evidence, and of the fluctuations which appear in the Greenwood and Batley data on factor shares, it would be unwise to conclude that this data demonstrates the absence of significant factor substitution, although it certainly does not demonstrate that factor substitution was taking place.

The second set of evidence from the Greenwood and Batley data suggests, however, that factor substitution on a significant scale was not taking place. If factor substitution had taken place, then it is likely that the utilisation by the firm of the different types of labour available to it, and consequently the relative wages of those types of labour, would have altered. It is of course possible that changes in organisation, in particular, might produce reductions in the use of all types of labour, thus preserving the same relative usages; a possible example is the transfer of responsibility for hardening the cutting tools from each workman to a central toolshop, which was certainly done in some workshops at this period.[19] On the other hand, such changes would have a once-for-all character, which should

19 Parsons, F. History of the Institution of Mechanical Engineers (London, 1947), p.151.

show up in the evidence as a sudden jump in productivity, rather than a long run trend of the type which is being considered. In all except such exceptional cases, therefore, one would expect factor substitution to have affected the use made by the firm of different types of labour, particularly since the wage differentials would have constituted a considerable incentive to the firm to substitute less skilled for highly skilled labour.

Greenwood and Batley classified their labour into five types, boys, planers and borers, turners and fitters, boy joiners, and men joiners. The productivity of labour could have been enhanced by two methods, firstly by using more of the less skilled labour, thus cutting labour cost per unit of output, or secondly by paying a particular group more to enhance its production per man-hour. The first method would result in a change in the proportions of each class of worker used on a given job, and the second method would result in a change in the relative wage-rates.

It is clear from table 6, 1 that very little if any substitution of one category of labour for another took place. Had it done so, the trend in production per man-hour using total hours would have diverged from the trend in production per man-hour calculated from hours weighted by relative wage-rates. It will be recalled that these trends were in fact very similar. The actual proportions of the total number of hours worked attributable to each of the five categories is shown in table 6, 3, and it is clear that these proportions are very stable over the entire period of 45 years. These figures in fact suggest that there was no significant change in the utilisation of labour by the firm over the whole period.

Year	Boys	Planers & Borers	Turners & Fitters	Boy Joiners	Men Joiners
1856	20	15	64	0	1
1857	27	20	51	0	2
1858	26	20	53	0	2
1859	20	21	52	1	6
1860	28	20	49	0	2
1861	30	20	45	0	4
1862	31	21	43	0	4
1863	26	20	50	0	4
1864	29	22	45	1	4
1865	31	20	46	1	2
1866	19	16	54	2	9
1867	22	22	53	0	3
1868	23	19	54	1	3
1869	22	16	58	1	3
1870	22	19	54	1	5
1871	22	15	59	1	3
1872	27	11	60	1	2
1873	27	9	62	1	1
1874	25	11	61	1	2
1875	25	10	60	2	4
1876	21	6	58	4	11
1877	29	8	56	2	4
1878	28	20	46	1	4
1879	19	33	44	1	4
1880	10	38	46	1	5
1881	17	34	45	0	3
1882	16	22	54	1	7
1883	24	18	55	0	4
1884	24	17	50	1	8
1885	21	17	52	1	8
1886	26	16	51	1	6
1887	21	19	53	1	6
1888	23	24	50	1	3
1889	24	19	54	0	2
1890	23	15	59	0	2
1891	22	16	58	1	3
1892	29	15	55	0	1
1893	23	14	59	1	3
1894	24	14	57	1	4
1895	19	19	57	1	4
1896	21	12	63	1	4
1897	21	12	63	1	3
1898	23	18	53	1	4
1899	23	18	54	1	3
1900	17	13	56	2	2

TABLE 6,3 **Proportions of total hours worked by each** category of labour, Greenwood and Batley Ltd., 1856-1900.

Totals do not necessarily sum to 100 in each year, because of rounding errors.

This suggestion is confirmed by an examination of the relative wage-rates of these five types of labour. These are given in table 6, 2. It is clear that these relative wages remained very constant over the period; although wage increases were not, as a rule, granted to all types of labour simultaneously, the boys in particular lagging behind, the differentials were normally adjusted, to return to their previous level, within a few years, so that very nearly the same relative wages were paid at the end of the period as at the beginning. It seems therefore, that it was not possible for Greenwood and Batley to reduce labour costs per unit of output by reducing differentials for skill, however profitable it might have been for them to do so. These figures are in fact confirmation, if negative confirmation, of the lack of significant factor substitution, since it does not seem likely that, had substitution taken place, these relative wage-rates would have remained so stable over such a long period.

It is possible that some form of concealed substitution could have taken place; if the skills and capacities, and the machinery available to, the labour force, was changing, but due to inertia or tradition the titles of different types of labour remained constant, then the changes might not be obvious from the cost books of the firm. On the other hand, it is not easy to think of any form of substitution which, over the long term, could affect all types of worker simultaneously, allowing such stability in both the utilisation and the relative wages of the five types. The stability can therefore be regarded as further evidence against large scale factor substitution as a cause of the observed trends in labour productivity.

Period	Boys	Planers & Borers	Turners & Fillers	Boy Joiners	Men Joiners
June 1856–April 1857	10.1	20.2	30.4	10.2	29.1
April–May 1857	10.1	20.2	30.2	10.1	29.6
May 1857–Dec. 1859	10.0	20.3	30.1	10.0	30.7
Dec. 1859–May 1860	10.2	20.5	29.5	10.2	29..
May 1860–Dec. 1864	10.5	21.0	2..	10..	29.1
Dec. 1864–July 1865	10.3	20.7	28.7	10.3	29.9
July 1865–April 1870	10.2	20.4	28.4	10.2	30.7
April 1870–July 1870	9.9	20.8	28.4	9..	31..
July 1870–March 1871	10.2	20.4	28.4	10.2	30.7
March 1871–Aug. 1871	9.8	20.3	28.4	9.8	31.1
Aug. 1871–Nov. 1872	9.5	21.0	28.4	..5	31.6
Nov.–Dec. 1872	10.3	20.5	27.3	10..	30.1
Dec. 1872–May 1873	9.9	20.3	28.1	9.9	31..
May 1873–Dec. 1878	10.3	20.6	27.3	10.3	30.1
Dec. 1878–March 1882	10.1	21.2	2..3	10.1	30.1
March 1882–May 1884	10.0	22.0	28.0	10.0	30.0
May 1884–July 1885	..9	21.8	28.7	9.8	29.7
July 1885–Jan. 1886	10.0	22.0	28.0	10.0	30.0
Jan. 1886–March 1886	9.9	21.8	28.7	.9	29.7
March 1886–June 1886	10.0	22.0	28.0	10.0	30.0
June 1886–Jan. 1890	..9	21.8	28.7	9.9	29.7
Jan. 1890–May 1890	..9	21.7	29.1	9.9	29.6
May 1890–Dec. 1890	..7	21.4	28.	..7	30.
Dec. 1890–April 1891	9.7	21.3	2..0	9.7	30.
April 1891–March 1892	9.5	21.0	..6	9.5	31.4
March 1892–August 1892	..0	20.6	2..7	.	31.6
Aug. 1892–Oct. 1895	9..	20.2	2..7	..6	31.7
Oct. 1895–Nov. 1895	9.8	20.5	28.3	9.8	30.7
Nov. 1895–March 1896	..	20.7	28.6	.4	31..

continued :

Period	Boys	Planers & Borers	Turners & Fillers	Boy Joiners	Men Joine
March 1896–June 1896	[illegible]	20.5	30.1	[illegible]	30.[illegible]
June 1896–Oct. 1896	9.5	19.9	29.9	9.5	31.3
Oct. 1896–March 1897	9.5	20.0	30.5	[illegible].5	30.5
March 1897–March 1899	[illegible].2	20.2	30.[illegible]	[illegible].2	31.3
March 1899–Dec. 1900	9.5	20.0	30.5	[illegible].5	30.5
Dec. 1900–Nov. 1901	[illegible].5	[illegible].0	30.5	[illegible].5	30.5

TABLE 6 2. Relative wage-rates of Greenwood and Batley workers, 1856–1900, (totals across columns = 100).

Note : The dates in column 1 refer to the month in which the work was started, rather than ordered or delivered.

Although, as Salter demonstrates, the movements in factor shares and in the utilisation of labour which have been described are still consistent with a considerable degree of factor substitution having actually taken place, they certainly do not demonstrate that it did take place. The evidence of the variables connected with labour, in particular, suggests that any factor substitution which did take place must have been of a curious type, since it apparently did not affect the distribution of tasks between workers, the description of their tasks, their relative wages rates, or any other discernible variables. It is therefore necessary to look at other possible explanations, apart from factor substitution, for the changes in the productivity of labour which have been described.

A second possibility is that the changes were the result of the achievement by the firm of economies of scale or specialisation. It was argued by contemporary observers that the competitive advantage of the American over the British machine tool industries in this period was the result of the achievement of economies of this kind by the American machine tool producers. It is clear, from the discussion of this subject in chapter 4, that this explanation has many difficulties, but it is probable that some economies of scale or specialisation were secured in America, and could have been secured in this country. It is therefore possible that it was by such means that Greenwood and Batley achieved their increase in labour productivity.

Unfortunately, the nature of the evidence is such that no conclusive judgment can be given. If production expressed as cwts. produced per man-hour is regressed upon

numbers of cwts.produced, an R^2= .5500 (.5524 if the weighted hours measure is used), is obtained. This is some confirmation of the existence of economies of scale. It will be recalled, however, that the method of compilation of the data set used in this chapter involved the exclusion of all cases for which some information was missing from the order or cost books. This omission does not seriously affect calculations of productivity change, since the remaining sample size is still very large, but it does almost certainly affect calculations of economies of scale, since if such economies did exist, then many of the orders omitted because of missing information must have contributed to their achievement.

On the other hand, the coefficient of variation quoted above (R^2=.5500) provides some support for an explanation based oneconomies of scale. It is also possible to reason that such economies could have been achieved in two ways. Firstly, there is evidence that a number of machines, particularly straight milling machines, edge milling machines cutter grinding machines, and rifling machines, were made in large numbers. Unfortunately, it is impossible to show that this resulted in a reduction of unit costs, because the range of sizes made remained large, so that comparisons over time are difficult to make. There must, however, have been economies in design costs, and such economies, together with presumably a greater familiarity of the labour force with machine tools which they made in large numbers, must have aided an increase in productivity of all factors.

Secondly, the cost books show that an increasing number of sectional parts were being made centrally and then

supplied as needed to the fitters constructing a particular machine. The cost of such parts was included within the materials cost of each order, as the result of an internal book-keeping transfer within the works. The result of an increase in the number of sectional parts used, as opposed to their manufacture for a particular order, was thus to shift costs from direct labour costs to materials cost in the accounting procedure, and consequently to reduce the number of hours of direct labour recorded for each order. In the extreme case, therefore, such a transfer could be responsible, because of the method of accounting, for the change in the productivity of direct labour which appears in the records, although no real change need have taken place. Fortunately, it does not appear that this extreme was reached; the stability of factor shares, referred to above, is evidence that it did not occur, and the cost of parts supplied, including castings, remained throughout the period a small part of materials costs. (Direct measurement of this was not possible, owing to the impossibility of collecting data on all metal costs in detail, and this statement is therefore based on an impression of the cost books). However, insofar as central manufacture of parts was carried out in the works, then a real increase in the productivity of labour, through economies of scale, and the use of similar parts on a variety of machines, was probably achieved.

A further reason for attributing much of the increase in labour productivity to the achievement of economies of scale is that such an explanation would account for the tendency of all unit costs to move together over time, and also for the use of different types of labour to remain stabl

Economies of scale are economies which save all factors, and which affect all sections of the labour force, and are therefore consistent with only minor changes in the relative strength of each factor or the relative use of all types of labour. This is not of course to argue that, for these reasons, the increases in productivity can definitely be attributed to economies of scale; it is simply to argue that the evidence is not inconsistent with such a view.

It thus appears that, on the basis of the Greenwood and Batley evidence, significant factor substitution is not a plausible explanation of changes in the productivity of labour in the machine tool industry, while the achievement of economies of scale is a more plausible explanation. The third possibility to be considered is that the increase in labour productivity was in fact a result of pure technical change, that is a shift, or shifts, over the period, to new production functions. It has already been suggested, in the chapter concerned with the technical development of machine tools during the nineteenth century, that there were major technical improvements in machine tool design which widened the possibilities of machining metal accurately, which greatly increased the speed with which metals could be machined, and which reduced the costs of such machining. Thus it is clear that technical change did occur in the machine tool industry; the question remains whether it was significant in causing increases in the productivity of labour, of the type and speed which have been observed.

The major justification for attributing much of the change in labour productivity to technical change lies in

A	Unit = 1 Machine-Tool	1	2	3
1	Labour cost per unit	1.0	+0.8999	+0.9219
2	Materials cost per unit		1.0	+0.8270
3	Gross margin cost per unit			1.0

B	Unit = 1 cwt. of achine-Tool	1	2	3
1	Labour cost per unit	1.0	-0.1235	+0.7671
2	Materials cost per unit		1.0	-0.0595
3	Gross margin cost per unit			1.0

TABLE 6, 4. Matrices of correlation coefficients between factor costs per unit of output, Greenwood and Batley 1856-1900.

fact in the difficulty of attributing much of that productivity change either to factor substitution or to economies of scale. Technical change is thus, as usual, left as the residual factor, difficult if not impossible to measure, but still important. It is also a plausible explanation because of the known improvements in machine tool design known to have been made during the period, even if these improvements did not greatly alter the physical appearance of the major types of tools.

It can therefore be tentatively concluded that the major source of increases in the productivity of labour in the operations of Greenwood and Batley, and by extension in the machine tool industry in Britain as a whole, came from improvements in technical knowledge, combined in all probability with the achievement of some economies of scale. The evidence of Greenwood and Batley supports therefore the conclusion reached by Salter that :

> "... primary emphasis must be placed on technical progress and economies of scale. These are causes of labour productivity which extend their influence to all factors and so can account for the behaviour of costs. Increases in the personal efficiency of labour and factor substitution cannot explain the data by themselves although, in the case of factor substitution at least, it is possible, (and indeed likely) that an important contribution has been made to the observed increase in productivity."20

While it is necessary to add to this conclusion all the reservations made by Salter, it is at least encouraging for this theory of productivity change in that it appears to be plausible in the context of a single firm in the nineteenth century as well as applicable to twenty-eight industries in the twentieth century.

20 Salter, W.E.G., <u>op.cit.</u>, p.144.

It has been shown in the last section of this chapter that substantial changes in the productivity of labour were achieved by Greenwood and Batley between 1856 and 1900. Such substantial changes must have had effects upon the firm itself and upon its customers in the engineering industry as a whole, and it is the purpose of this section to establish what some of these effects were.

Increases in the productivity of labour, and therefore decreases in the unit labour cost of the output of machine tools, could have been reflected in pricing policy of the firm in two ways. Either the reduction in unit labour costs could have been reflected in lower unit prices, thus passing the benefit of the productivity increases on to the customer for machine tools, or prices could have remained stable, the productivity increases accruing to Greenwood and Batley in the form of increased margins. The evidence in fact suggests that the major part of the benefits accruing from productivity increases were passed on to the customers. It is clear that, if this was so then the evidence should demonstrate a close inverse relationship between price per unit and units produced per man-hour. The importance of labour cost as a factor in total cost, in this relatively labour-intensive industry, also suggests that there is likely to be a close connection between labour cost, and through it labour productivity, and prices. The relationship can be tested by regressing price per unit upon units produced per man-hour. (Because of the difference in scale of the two variables, logarithms were used in this regression, and the first differences of the log. variables were taken, to guard against the danger of auto-correlation).

The results of this regression analysis were, for price per cwt (y) regressed upon cwts. produced per weighted man-hour (x) :

$$y = 0.00155 - \underset{(0.06856)}{0.89064}\,x \qquad R^2 = .89064 \qquad D\text{-}W = 2.29202.$$

and for price per machine (y) regressed upon machines produced per weighted man-hour (x) :

$$y = 0.00570 - \underset{(0.05495)}{0.86721}\,x \qquad R^2 = .92504 \qquad D\text{-}W = 2.26484.$$

In both cases, a slightly better fit was achieved by using the measurement of man-hours weighted by wage-rates. (Similar regressions using the total of man-hours produced R^2 estimate of .89688 and .92258 respectively).

It will be recalled that it was argued in the chapter concerned with Greenwood and Batley's relationships with their customers that, on average, prices for tools sold to foreign customers were higher than prices for machines sold to customers in this country. It might therefore be expected that the relationship between labour productivity and price would be disturbed by this apparent higher pricing of some machine tools. Calculation of unit prices for machine tools and for cwts. of machine tools, on the basis of the reduced data set used in this chapter, confirms that there is a difference, significant at the 5% level, between home and foreign prices. This difference is not however enough to affect seriously the relationship between labour productivity and price. Calculations of this relationship for data sets split by destination of the orders were, for reasons of time, possible only with the raw variables, and thus the correlation coefficients are lower than they would have been had logarithmic values been used, but they

are still significant, and display the inverse relationship which is expected. The results were :

Variable 1	Variable 2	R Home	R Abroad
Price per cwt.	Cwts. per (total) hours	-.6757	-.6548
Price per cwt.	Cwts. per (weighted) hours	-.6739	-.6577
Price per machine	Mach. per (total) hours	-.5322	-.6710
Price per machine	Mach. per (weighted) hours	-.5487	-.6814

The significance of these results, demonstrating a close inverse relationship between movements in labour productivity and movements in price of machine tools, is that much of the benefit of increased productivity in the production of machine tools is being passed on to the consumer, either through lower prices or through stabilisation of prices at a lower level than would have been possible had an increase in labour productivity not been achieved. This caveat is necessary because, as will be remembered, price per machine did in fact increase over the period. The growth in labour productivity enabled price per cwt. of machines produced to be reduced over the period, the linear trend being

$$y_t = 4.81734 - 0.04220\ x_t$$

yielding a growth rate over the 45 year period of -1.1% per annum. The rise in costs per machine, however, was reflected in a growth rate for that variable of 2.9% per annum, the linear trend being

$$y_t = 47.49171 + 3.27479\ x_t\ .$$

Some confirmation of the view that productivity increases were being passed on to the consumer may also be found in the dismal profit record of the firm which was described in the last chapter.

Customers for machine tools were thus receiving their tools at either a lower price per unit, if price per cwt. is used as a measure, or at only a slightly higher price, if price per machines is used. Secondly, since the measurement on which these calculations were based assumed no significant change in the product, they were also receiving all the benefit of the increasing technical capabilities of the machine tools themselves, whose increasing capacity was reflected, if the argument above is correct, in the rise in labour productivity.

Greenwood and Batley were among the 'best-practice' firms in the machine tool industry during the years to which these productivity change calculations relate. It is likely therefore that the increases in labour productivity were also achieved by other leading firms in the industry, and that similarly the benefits of such increases were passed on to customers of these other firms. Such other customers would also be benefitting from the technical improvements in machine tools which, if only gradually and with the assistance of economies of scale, were bringing about these productivity changes. If this is so, then the British machine tool industry must have been making a substantial contribution to increasing productivity in the metal-working industries.

The size of this contribution, if it is adequately

represented by the calculations on the basis of the Greenwood and Batley data, may be measured by comparing the productivity changes found in these records with the aggregate productivity calculations made for the British economy in this period. Dr. Aldcroft, for instance, has printed estimates of productivity change in industrial production, based on the Hoffmann indices, which show long-term growth rates per annum of 1.3% between 1860/61 and 1879/80, and of 0.09% between 1880/81 and 1909/10. The largest long-term or decadal growth rate shown in Aldcroft's calculations is that of 1.72% per annum between 1885/6 and 1889/90.[21] By contrast, the Greenwood and Batley figures suggest a rise in productivity over the whole period from 1856 to 1900 of 2.3% or 2.4% (depending on the method of calculation used).

It is clearly hazardous to compare estimates drawn from the whole of British industry (and based on statistics whose use in this way is of dubious validity) with estimates drawn from the experiences of a single firm. The Greenwood and Batley estimates relate to 'best-practice' machine tool building, and it is possible that the less advanced firms in the industry were experiencing slower rates of productivity increase. At the same time, the estimates which have been presented in this chapter go some way towards redressing an over-pessimistic view of the contribution of the machine tool industry to British industrial growth in this period.

21 Aldcroft, D.H. and Richardson, H.W. The British Economy, 1870-1939. (London, 1969) Section B, chapter 2, by D.H. Aldcroft 'The Problem of Productivity in British Industry, 1870-1914', p. 128.

Conclusion.

The machine tool industry occupies a central place within the engineering and metal-using industries. The sale of machine tools represents an important means of transmitting technical knowledge within industry, while improvements in machine tools can result in improvements in productivity in a wide range of customer industries. The improvement in machine tools during the nineteenth century was a major cause of the increases in output and of improvements in the quality of metal goods in that period, while the exports of machine tools constituted an important part of British foreign trade.

This work has been largely concerned with the elucidati in detail of these broad themes, and with demonstrating exactly the various linkages of the machine tool industry with the rest of the economy. The major conclusions of this study can be summed up under three main headings, the contribution of the machine tool industry to technical change, the role of the machine tool industry in foreign trade, and the achievement, through improvements in machine tools, of increasing productivity in manufacturing industry.

The subject of the transmission of technical knowledge is one which has received increasing attention from economic and economic historians in recent years, both in theoretical studies and in the context of the debate on the differences in technology between Britain and America in the nineteenth century. In general, however, in spite of this increased attention, the major focus of interest has been upon the transmission and adoption of improved technologies either

in the aggregate, on the scale of national economies, or within single industries. Little attention has been paid either to the role of such service industries as that of the consulting engineer, or to the role of the machine tool firm in acting as a consulting engineer, and thus bridging gaps either between best-practice and worst-practice firms within an industry, or between industries which have similar technical problems but are manufacturing different types of output. Nor has much attention been paid to the importanc in the transmission of technical knowledge of the multi-product firm, able to transfer improvements in the technology of one product to the problems of another.

The studies which are grouped in chapter 2 of this work, together with the detailed studies of the relations of Greenwood and Batley with their customers which form part of chapter 5, suggest that these aspects of technical change deserve further study. The linkages which are demonstrated in chapter 2 to have existed within the different sections of the engineering industry were, potentially or actually, channels for the transmission of technical knowledge, and the existence of such linkages between superficially distinct groups of producers suggest that the engineering industry at last may have had a structure radical unlike the traditional Marshallian framework of the single-product firm within which technical change is normally studied. Furthermore, the flexibility exhibited in the more detailed study of the size of the machine tool industry, by which changes in output could be achieved by firms switching into and out of the industry, suggest that analysis of industrial change in terms either of single-product firms or of industries in which entry is assumed to be of newly

created firms, and exit to signalise the disappearance of th firm, may be highly misleading. The highly fluid structure of engineering in this period, revealed in chapter 2, may have been far from the disadvantage to the British economy that it is often thought to have been; lack of specialisation in other words, had considerable advantages.

Lack of specialisation, expressed in the multi-product firm, was also an advantage to an individual firm, as can be seen in the history of Greenwood and Batley's production of machine tools. The willingness of the firm to undertake the manufacture of a wide range of armaments machinery, documented in chapter 5, enabled it to sell large quantities of this type of machinery widely both at home and abroad. Within such a multi-product firms, too, experience gained in the manufacture and use of one type of machinery could be rapidly used to advantage in making and selling such machinery to other customers; an example of this is the milling machine which Greenwood and Batley made initially for the arsenals, but soon sold widely to other types of customers.

The role of the machine tool industry in international trade was the theme of chapter 4 of this work, and was also considered in the sections on Greenwood and Batley. The discussion in chapter 4 demonstrated once again how difficult it is to assess in sufficient detail the causes and consequences of trade flows in particular products in the nineteenth century. One of the major lessons of this attempt to do so is that the perceptions of contemporary observers, particularly those concerned with technical rather than commercial

considerations, may be extremely misleading, and that studies of English foreign trade in the period should make use of the trade statistics of foreign countries in an attempt to reduce the possibility of such mistakes. More generally, it is clear from the discussion in chapter 4 that the attempt todiscover mono-causal explanations of the relative decline of Britain in international markets during this period is doomed to failure. On one level, the defeat of British machine tool makers in the French market can be seen as the result of the coincidence of a series of unrelated occurrences having little to do with the normal explanations of the American invasion in terms of salesmanship, technical expertise or changing factor prices. Even if these latter explanations can be used in a longer-term analysis, in the short-term, and as a determinant of the timing of the export invasion, they were unimportant.

The third major conclusion of this study relates to the results discussed in the last chapter, concerned with the degree of productivity change in the machine tool industry. These results suggest, as was pointed out in the last paragraphs of that chapter, that the rate of growth of productivity in best-practice machine tool making was considerably in advance of the rates of growth of productivity in manufacturing industry as a whole. If these growth-rates for productivity in machine tool production are reliable, if they were achieved at least partially by technical advances, and if through lower real prices and improved machine tools these advances were spread widely through the metal processing industries, then it may be necessary to revise some established ideas about the backwardness of British engineering at this period and about its effects on aggregate national growth. To

explore this as fully as it deserves would require further study, firm by firm, of the machine tool industry and of its major customers, in an effort to establish whether Greenwood and Batley were in some way exceptional, and whether the customer industries in fact received benefits from the purchase of the new machine tools.

In these three major respects, industrial structure and its implications for technical progress, foreign trade, and the rate of growth of productivity, this study has come to conclusions more favourable to the machine tool industry than much contemporary and recent comment has been. This may be because, as was explained in the Introduction, the main emphasis of this study has been upon the performance of the machine tool firms in the market, and in their relations with other industries, rather than with their internal operations; it is possible that more detailed investigation of their organisation and methods, were the sources available would reveal more to their discredit. Clearly this study would have benefited from comparisons with other engineering industries, or with other firms than Greenwood and Batley within the machine tool industry, and in the absence of such comparisons the significance of the conclusions reached is difficult to assess.

The emphasis of this study has also been upon the detailed investigation of quantitative sources for the history of the industry. There are two reasons for this emphasis, the first that there is a lack of sufficient contemporary comment on the industry, the second that traditional non-quantitative approaches to business history have suffered from a concentration on the leading firms,

while industry is composed of many more than the exciting, technically progressive and record-keeping businesses. The utility of the quantitative approach can only be judged by the results that have been presented, and I can only hope that this study has justified the rejection of the view of a Mr. J. Richards, who told the readers of the American Machinist in 1899 that "It is not probable that a history of machine tool making will ever be written or published, at least not in an accurate and impartial way... the expense and time required to collect and collate the facts over such a wide field are not warranted..."[1]

1 Richards, J. 'Machine-Tools', American Machinist, American edition, Vol. 23, May 4, 1899, p.379.

BIBLIOGRAPHY.

I. Manuscript Sources and Catalogues.

Appleby Brothers Ltd.	: Catalogues, 1863,1869,1878,1897.
Archdale, James and Co.	: Partnership Documents 2/4/1878, 7/12/1894 and 18/10/1897.
	Sales Books 1874-5, 1878-1890.
	Capital Accounts 1878-1893.
	Trading Accounts 1885-1893,1895, 1896.
	Balance Sheets 1885-93,1895,1896 1897.
	Catalogues, 1884,1889,1894,1904, 1906,1911.
	Private Letter Book 7/10/1889,- 3/3/1891.
Brown and Sharpe Manufacturing Co.	: Sales Records to 1914.
Butler Machine Tool Co.	: Order Books, 1889-1914
	Foundry Profit and Loss Account: 1889-1901.
	Balance Sheets 1886-1909.
	Catalogue 1905.
	Typescript synopsis of history of firm, 1957.
	Replies to enquiries of old employees.
Collier, William and Co.	: Price List. 1856.
Greenwood and Batley Ltd.	: See list of material in chapter 5 and appendix to chapter 5.
Herbert, Alfred Ltd.	: Balance Sheets, 1887,1888,1889, 1892-4,1895-1914.
	Trading Accounts 1888-9,1891-19
	Miscellaneous letters and documents, list of shareholders, do of property etc.

Herbert, Sir Alfred	: Miscellaneous papers in the possession of Ian Helliek, Esq., including 'Machine Chasers' a manuscript autobiography of Sir Alfred Herbert.
Holroyd, John and Co.	: Manuscript history in the possession of the firm. Catalogue, 1895.
Jones, W.A. and Shipman	: Catalogues, 1909,1911,1914.
	Page-book, June 1903-June 1906.
Machine Tool Trades Association	: Minutes of the Executive Committee and Council, 1919.
Nasmyth, James	: Material in the James Nasmyth Collection in the Eccles Public Library, Lancashire.

II. Publications of Machine Tool Firms.

Appleby Brothers : Appleby's Illustrated Handbook of Machinery (London, 1897).

Archdale, James and Co. Ltd. : Archdale Machine Tools. 1868-1948. (n.p., 1948).

Berry, H. and Co. Ltd. : 65 Years of Progress (n.p., n.d.)

Britannia Co. : Screws and Screw Making by Rev. J. Lukin, (Colchester, 1891).

Brown and Sharpe Manufacturing Co. : Construction and Use of Universal Milling Machines (Providence, R.I. 1882).

Churchill Machine Tool Co. : The Story of the Churchill Machine Co. (Manchester, 1956).

Dean, Smith and Grace Ltd. : A Little Farm Well Tilled by E. Grierson, (n.p., n.d.).

Sellers, William and Co. : A Treatise on Machine Tools etc., as made by Wm. Sellers and Co. (Philadelphia, Penn., 1877)

Stirk, John and Sons Ltd : Peerless Planes and Plows (Halifax 1938).

XXI. Unsigned Articles and Letters in Periodicals.
(Titles of articles are shown in quotation marks. In the case of untitled articles the main subject of the article is given)

American Machinist : German Machine Tools 1.4.1882.

American Imports of English Machine Tools 6.5.1882.

American and British Machine Tool Industries 26.1.1884.

Machinists Wages in Europe and America 25.10.1884.

Review of 'James Nasmyth - an Autobiography', by Samuel Smiles. 20.12.1884.

Role of the consulting engineer in Europe and America 8.8.1889.

Sales of American Machine Tools in Coventry 23.11.1895.

Sales by Charles Churchill and Co. 7.2.1895.

History of Charles Churchill and Co. 22.10.1896.

American Machine Tools in Coventry 11.2.1897.

Letter from H. Austin, (Manager of Wolseley Sheep Shearing Co. Ltd.) on American Machine Tools 25.3.1897.

Joshua Buckton and Co. 4.11.1897.

Letter from Charles Davis (President of Davis and Egan Machine Tool Co.) on American Machine Tools in Europe 13.1.1898.

Memoir of James Platt 13.1.1898.

'American Tools in England' 20.1.1898.

Letter from H. Austin on specialisation in the making of machine tools 3.3.1898.

Reply from J. Horner to letter from H. Austin 7.4.1898.

Letter from Charles Churchill on sales of American machine tools to Europe 30.3.1899

American Machinist (continued)

: Sales of American Machine Tools to Europe 13.7.1899.

Specialisation in machine tool making in Europe and America 26.5.1900.

Beyer, Peacock and Co. 31.8.1900.

'The Works and some of the Products of Alfred Herbert Ltd.' 17.10.1901. 24.10.1901. 31.10.1901.

Letter from J. Redman on Halifax Machine Tools 29.10.1903.

Review of 'Engineering Reminiscences' by C.T. Porter, 20.8.1903.

Geographical Distribution of English Machine Tool Makers, Jan/June 1914, p.564.

British Exports of Machine Tools 31.12.1914.

American Machinist (European Edition)

: Decline in sales of American machine tools to Europe 6.7.1901.

British exports and imports of machine tools 13.1.1912.

British exports and imports of machine tools 5.10.1912.

Colliery Guardian : Report of address by Samuel Dixon on machine tools 2.4.1896.

Engineer : 'A tour through the Provinces - Nasmyth Works' 23.5.1856.

'A tour through the Provinces - Fairbairn Works' 13.6.1856.

State of trade of W.G. Armstrong works, Elswick 3.1.1862.

Whitworth Machine Tools 30.1.1863.

Engineer (continued)

: Letters on Whitworth Machine Tools	13.2.1863.
'English Criticisms on American Engineering Work'	12.12.1890.
'Machine Tools'	3.10.1897.
'Machine Tools in the Future'	17.10.1897.
'English and American Methods in the Engineering and Iron Trades'	21.1.1898.
'English and American Machine Tools'	2.12.1898.
'British and American Machine Tools :	
I. A comparison of the conditions surrounding the trade,'	27.10.1899.
II. Their comparative efficiency'	1.12.1899.
III. Their comparative durability and cost'	8.12.1899.
IV. Their comparative cost (continued)'	15.12.1899.
V. Comparative Facilities for Delivery and Methods of Selling'	29.12.1899.
'American Machine Tools'	16.2.1900.
'English and American Methods'	31.8.1900.
'German Machine Tool Industry'	13.6.1902.
'Engineering in 1905'	5.1.1906.
'Worth Valley Tool Works, Keighley'	20.5.1906.
'Engineering in 1906'	4.1.1907.
'The German Engineering Industry in 1906'	22.3.1907.
Birmingham Small Arms Company works	10.5.1907.
'Nasmyth's Centenary'	18.9.1908.
George Richards and Co.	1.8.1913.

Engineering

: 'Engineers' Tools'	25.10.1867.
Memoir of Thomas Greenwood	28.2.1873.
Memoir of William Muir	24.8.1888.

Engineering (continued)

'Messrs. Hulse and Co.'s Machine Tool Works'	27.7.1894.
'The Gresley Iron Works (Smith and Coventry)'	27.7.1894.
'American Machine Tools'	13.12.1896.
Works of Alfred Herbert Ltd.	30.12.1898.
Beyer Peacock and Co.	4.1.1907.
Works of Alfred Herbert Ltd.	22.7.1910.
Works of John Lang and Co.	6.6.1913.
'The Foreign Trade in Machine Tools'	25.9.1914.

Engineering Review:

Craven Brothers	20.10.1894.
Luke and Spencer Ltd.	20.10.1894.
J. Muir and Co. Ltd.	20.10.1894.
George Richards and Co.	20.10.1894.

Engineering Supplement to 'The Times'

British backwardness in machine tools	1.3.1905.
Works of Fairbairn MacPherson Ltd.	25.7.1906.
The Italian catalogue produced by Alfred Herbert Ltd.,	27.7.1906.
Delays in delivery of American machine tools	16.1.1907.
Engineering Wages in Manchester	12.6.1907.
Machine tool production in Manchester	3.7.1907.
Influence of the Motor-Car on Machine Tools	25.9.1907.
Machine tools for the motor and cycle trades	8.1.1908.
Machine tools in the B.S.A. works	15.1.1909.
Production of machine tools in the Midlands	4.3.1909.
James Archdale Ltd.	4.3.1909.

Engineering Supplement to 'The Times' (continued)

: Bateman's Machine Tool Co., Leeds 1.3.1909.

Alfred Herbert Ltd. 4.3.1909.

Depression in the Scottish machine tool trade 10.2.1909.

Brussels Exhibition of 1910 31.8.1910.

Olympia Exhibition of 1910 14.9.1910.

Manchester Exhibition of 1910 26.10.1910.

Recent changes in machine tool design and manufacture 22.2.1911.

Machine tool design 22.5.1912.

'Machinery and economy' 14.3.1912.

Machinery exports for U.S.A. and Great Britain 28.8.1912.

Olympia Exhibition of 1912 16.10.1912.

Halifax Evening Courier

: Obituary notice of James Ryder Butler 20.3.1917.

Iron Trade Review

: Milling machines in English engineering works 25.4.1901.

Machine tool salesrooms in New York 4.3.1909.

Machinery

: 'News from the Shops' appears in the majority of issues of this periodical from 5.10.1911 to 22.1.1914.

'The Exhibition at Olympia' 19.10.1912.

'College-trained engineers and employment' 24.10.1912.

'Price-listing of machine tools' 21.11.1912.

German exports and imports of machine tools 28.11.1912.

'The Machine Shop' 2.11.1911.

Machinery (continued)

:	'British and Continental Technical Education'	10.12.1913.
	'Iron Founders and Machine Tool Makers' Requirements	24.7.1913.
	'British Machine Tool Interests in China'	11.[illegible]
	'Home-made Machines'	30.10.1913.
	'Stability of the Machine Tool Business'	15.1.1914.
	'German Machine Industry'	15.1.1914.

Machine Shop and Engineering Manufacture

:	'Charles Churchill, 1865-1965'	March 1965.
	'100 Years of Machine Tool Building'	June 1965.

Proceedings of the Institution of Civil Engineers

:	Memoir of Charles Frederick Beyer	XLVII, p.390.
	Memoir of Thomas Greenwood	LXXVIII, p.311.
	Memoir of Joseph Whitworth	XLI, p.429.
	Memoir of William Whitworth Hulse	CXXVIII, p.347.
	Memoir of George Greenwood	CXXXIII, p.399.

Proceedings of the Institution of Mechanical Engineers

:	Memoir of Andrew Shanks	1870.
	Joshua Buckton and Co.	1882, p.454.
	Smith, Beacock and Tannett	1882, p.460.
	Memoir of Robert Wilson	1885, p.29.
	Memoir of Sir John Anderson	Aug. 1886, p.460.
	Enfield Arms Factory	Aug. 1886.
	Memoir of Sir Joseph Whitworth	Feb. 1887, p.152.
	Memoir of Edward Fletcher	Aug. 1887, p.467.

Proceedings of the I. . . . (continued)

	Memoir of William Muir	July, 1888, p.140.
	Memoir of Richard Peacock	Jan. 18 .
	Memoir of Manasseh Bledhill	May 1889, p.267.
	Memoir of Hermann Ludwig Lange	July 1892.
	Beyer, Peacock and Co.	July 1894.
	Hulse and Co.	July 1894.
	William Muir and Co.	July 1894.
	Macnyth, Wilson and Co.	July 1894.
	Smith and Coventry	July 1894.
	Memoir of Benjamin Marsden	Feb. 1897, p.133.
	Memoir of J. . Hulse	Feb. 1897, p.137.
	Alfred Herbert Ltd.	July 1897, p.421.
	Memoir of James Platt	Nov. 1897, p.516.
	Memoir of J.W. Hulse	April 1898, p.315.
	Memoir of Thomas Graham Elliott	Feb. 1899, p.127.
	Memoir of Thomas Daniels	June 19 0, p.328.
	Memoir of Alfred Muir	May 1902, p.384.
	Memoir of John Shepherd	Dec. 1902, p.1039.
	Memoir of . Bates	May 190 , p.351
	Joshua Buckton and Co.	July 190 , p.590
	Memoir of William Craven	May 190 , p.3 3.
	Memoir of Charles Scriven	Feb. 1909, p.309.
	James Archdale Ltd.	July 191 , p.1307.
	Alfred Herbert Ltd.	July 1910, p.1365.
	. . Ford and Co.	July 191 , p.135 .
	Wolseley Tool and Motor Car Co.	July 191 , p.1357.

Radial Micro

	Biographical Note on William Asquith	June 1932.

Transactions of the American Society of Mechanical Engineers.

Yorkshire Post

: 'Dean, Smith and Grace Centenary' 12. .1963.

IV. Books and Signed Articles in Periodicals.

Aberconway, Lord (M'Laren C.B.E.) The Basic Industries of Great Britain. (London, 1927).

Addy, George, On Milling Cutters, P.I.M.E., October 1890.

Allen, G.C. The Industrial Development of Birmingham and The Black Country. (London, 1929).

Allen, G.C. British Industries and their Organisation. (4th ed., London, 1959).

Anderson, John, The Application of the Copying Principle in the Manufacture and Rifling of Guns, P.I.M.E., 1862.

Anderson, John, General Statement of the Past and Present Condition of the Several Manufacturing Branches of the War Office. (H.M.S.O., London, 1857).

Anon. Artisans Reports on the Vienna Exhibition. (Society for the Promotion of Scientific Industry, London, 1873).

Anon. British Engineers in the Twentieth Century. (Brighton, 1908.)

Anon. Halifax: a Commercial and Industrial Centre. (Halifax, 1915).

Anon. The Industry of Nations. Part III: A survey of the existing state of Arts, Machines and Manufactures: Machines. (S.P.C.K., London, 1855).

Anon. Lancashire: The Century's Progress. (Manchester, 1892).

Anon. Manchester as it is Today. (Manchester, c.1850).

Anon. Manchester of Today: Business Men and Commercial Interests. (Manchester, 1888).

Anon. Modern Industries. Artisans' Reports on the Paris Exhibition of 1867. (London, 1868).

Armytage, W.H.G. A Social History of Engineering. (London, 1961).

-trop, ..i. Machine Tool Buildin: in Britai., 2?; D.S. . Tools Ltd., ..itt: Green, Birmingh.. ac Inery and Production Mu.ineering, Feb. 16, 19..

Baines, E. History, Directory and Gazetteer of the County of York, Vol. 1. (Re-print.' edition, Newton Abbot, 1969).

Barker, Arthur H. The Manage.ent of .ll an.ricul. Workshops (Manchester, 1899).

Barlow, Peter. Treatise on the .anufacture m .c.inery of Great Britain. (London, 1836).

Becker, C. . High Speed Steel. (New York, 1910).

Becker, C. . The Influence of High Speed Steel on Recent Machine Tool Desi.n, Iron Trade Review, XLV, 27, Dec. 30, 1907, p.1123.

Benson, ..., The Early Machine Tools of Henry Maudslay Engineering, vol. 71, part 1, Jan. 18th, 1901.

Beresford, Admiral Lord Charles The Break-up of China (London, 1899).

Betts-Brown, Andrew (ed.) Engineerin: Facts and Figures for 1863.-5.-6.-7. (London and Edinburgh, 1864,-6,-7,-8).

Booth, William H. An English View of American Tools, American Machinist, 25, Nov. 6th, 1902).

Brackenburg, R.I. High-speed Tools and Machines to Fit Them R.I...h., July, 1910, 3, 929.

Broehl, .. (Jnr.) Precision Valley: the .achin. Tool Co.pany of Springfield, Vermont. (New Jersey, 1959).

Brown, Murray. .n the Theory and Measurement of Technical Chan.e. (Cambridge, 1966).

Brown, M and Rosenberg, N. Patents, Research and Technology in the Machine Tool Industry. PEC. J. Econ. Hist.

Brown, William . Innovation in the .achine Tool Industry QJE, vol. 71, 1957.

Brown, William . Innovation in the Machine Tool Industry Yale University, Ph.D. Dissertation, 1952. (unpublished)

Burn D.L. The Genesis of American Engineering Competition, Economic History, vol. II, 1931.

Burn, D.L. The Structure of British Industry, (Cambridge, 1958)

Burstall, F.W. A History of Mechanical Engineering (London, 1963).

Burn, R.S. Modern Mechanical Engineering and Machine Making. (Edinburgh, 1869).

Burton, F.J. Commercial Management of Engineering Works. (Manchester, 1899).

Buxbaum, Bertold Beitraege zur Geschichte der Fassungen Der Betrieb, II, 1919.

Buxbaum, Bertold Der amerikanische Werkzeugmaschinen - und Werkzeugbau im 18 und 19 Jahrhundert. Beitraege z.G., I, 1920.

Buxbaum, Bertold Der Deutsche Werk-zeugmaschinen - und Werkzeugbau im 18 und 19 Jahrhundert. Beitraege z.G., IX., 1919.

Buxbaum, Bertold Der englische Werkzeugmaschinen - und Werkzeugbau im 18 und 19 Jahrhundert. Beitraege z.G., XI, 1921.

Calder, John Rapid Production in Machine Work, [illegible] July 1910, III.

Cairncross, A.K. Home and Foreign Investment, 1870-1913. (Cambridge, 1963).

Camus, Charles L.L. A Treatise on the Teeth of Wheels, (2nd. edition, translated with an introduction on current practice in English shops, by John Isaac Hawkins) (London, 1837).

Carden, [illegible] observations among the [illegible] of Europe Scientific American, Feb. 25, 1911, p.193.

Checkland, S.G. The Rise of Industrial [illegible] England, (London, 1964).

Chretien, J. [illegible] nuel Complet des Machines-Outils, (Paris, 1866).

Chretien, J. Traite de la construction et de l'emploi des machines-outils. (Paris, 1866). (This, and the previous work, appear to be exactly the same in text and other respects.)

Chretien, J. Des machines-outils, leur importance, leur utilite, progres apportes dans leur fabrication, constates par l'Exposition Universelle de Londres en 1862. (Paris, 1863).

Chubb, [illegible]. Building Machine Tools in a Large English Shop (J. Parkinson and Son of Shipley) [illegible], American edition, Sept. 10th, 1914.

Clapham, J.H. Economic History of Modern Britain, vol. III. (2nd. edition, Cambridge, 1950).

Clark, D.K. The Exhibited Machinery of 1862 (London, 1864).

Cochrane, C.B. Modern Industrial Progress, (Philadelphia and London, 1904).

Colvin, Fred H. 60 Years with Iron and Machines (New York and London, 1947).

Cox, Harold (ed.) British Industries under Free Trade (London, 1903).

Coxon, Fred. Machine Tool Design - Modern British Practice Cassiers Magazine, XLVII, Nov. 1909, p.19.

Churchill, Charles The American Tool Business in Great Britain, American Machinist, American edition, 25, Nov. 6th, 1902.

Curzon, -., [illegible].P. Afghan Workshops at Kabul, Indian Engineer, XXII, 109, 9th Feb. 1895, p.86.

Davis, Charles American Machine Trade in Europe. American Machinist, European edition, Jan 13th, 1893.

Dickinson, H. W. Machine Tools in 1947, Engineering, 163, June 1947.

Dickinson, H. W. Richard Roberts, his Life and Inventions, Newcomen Soc., 25, 1945-7.

Dickinson, H. James Nasmyth and the Liverpool Iron Trade Transactions of the Historical Society of Lancashire and Cheshire, CVIII, 1956.

Dunham, Keith, The Gun Trade of Birmingham (Birmingham, 1955).

Dunsheath, P. (ed.) A Century of Technology (London, 1951).

Durbin, J. and Watson, G.S. Testing for Serial Correlation in Least-Squares Regression, Biometrika, Vol. 38, 1951.

Durfee, W.F. The History and Modern Development of the Art of Interchangeable Construction in Mechanism, American Society of Mechanical Engineers, Transactions, XIV, 1893.

Eversley, D.E.C. Industry and Trade, 1540-1880, In volume VII of The Victoria County History of Warwickshire, Birmingham

Fairbairn, Sir W. Useful Information for Engineers (London, 1856).

Feinstein, C.H. Income and Investment in the United Kingdom, 1856-1914, Economic Journal, June 1961.

Ferguson, E.S. Contributions to Bibliography in the History of Technology, Technology and Culture, 1961-3.

Ferney, L.V. The British Machine Tool Industry, Engineer, 1948.

Fleming, A.P.M. and Brocklehurst, H.J. A History of Engineering (London, 1925).

Fontaine, Hippolyte The Machinery of Hall at Vienna, 1873 (Paris, 1874).

Foster, F. Engineering in the United States (Manchester, 1906).

French, Sir James K. Machine Tools in Modern Engineering Practice. (London, 1911).

French, Sir James K. Engineering. (London, 1914).

Frevert, E.S. How Machine Tools are Sold, Machinery, Jan. 1907 p.243.

Frith, Henry, Triumphs of Modern Engineering. (London, 1891).

Galloway, D.F. Machine Tools. ch. 26 of the Oxford History of Technology, vol. V. (Oxford, 1958).

Garanger, Andre A. Petite Histoire d'une Grande Industrie. (Renilly-sur-Seine, 1961?)

Gilbert, K.R. The Science Museum: the Machine Tool Collection (H.M.S.O., London, 1966).

Gilbert, K.R. Machine Tools, ch. 14 of the Oxford History of Technology, Vol IV, (Oxford, 1958).

Girault, Arthur, The Colonial Tariff Policy of France. (Oxford, 1916).

Glover, F.J. The Growth of Transport in Leeds, Leeds Journal, 1956.

Glover, J.G. and Cornell, W.B. (eds.) The Development of American Industries. (New York, 1932).

Golob, Eugene O. 'The Meline Tariff': French Agriculture and Nationalist Economic Policy. (New York, 1944).

Gooch, Sir Daniel, Diary, 1816-1889. (London, 1892).

Green, H.E. Machine Tool Building in Britain :
19. W.E. Sykes, Ltd., Staines, Middlesex. Machinery, April 15th, 1964.
20. Churchill Machine Tool Co. Ltd., Broadheath, Manchester, Machinery, April 29, 1964.
21. Willson Lathes Ltd., Halifax, Machinery, June 3, 1964.
26. Craven Brothers (Manchester) Ltd., Machinery, Feb. 3, 1965.
28. Hayes Engineers (Leeds) Ltd., Machinery, June 9, 1965.

Greenwood, Arthur, Machine Tools, with Special Reference to American and German Practice as Compared with English Transactions of the Institution of Civil Engineers, CXXXVIII, p.419.

Greenwood, Thomas, Description of the Machinery for the Manufacture of the Boxer Cartridges, P.I.M.E., 1868.

Greenwood, Thomas, On Machinery for the Manufacture of Gun-stocks, P.I.M.E., 1862.

Haldane, J.W.C. Civil and Mechanical Engineering, popularly and socially considered.. (London and Liverpool, 1887)

Haldane, J.W.C. Life as an Engineer. (London, 1905).

Herbert, Sir Alfred, Memories, A Series of articles in Machine Tool Review, between 1953 and 1957.

Herbert, Sir Alfred, Shots at the Truth. (A. Herbert, Ltd., Coventry, 1948).

Hodgson, R.B. Machines and Tools employed in the Working of Sheet Metals. (Manchester, 1903).

Hogg, O.F.G. The Development of Engineering at the Royal Arsenal. T.N.E., vol. XXXII.

Horner, J. Some Lessons of the Stanley Show, American Machinist American edition, vol. 20, Dec. 30, 1897.

Horner, J. Some Recent Developments in British Machine Tool Design, Cassiers Magazine, XLI, Jan. 1912, p.36-7.

Howard, M.E. The Armed Forces, ch.VIII of F.H. Hinsley (ed.) The New Cambridge Modern History, vol. XI. (Cambridge, 1962).

Hubbard, G. The Development of Machine Tools in New England. American Machinist, 1923-4.

Hubbard, G. Metal Working Plants, Mechanical Engineering, vol. 52, April 1930.

Hunt, Robert, Handbook to the Industrial Department of the International Exhibition 1862. (London, 1862).

Knoop, Douglas, Industries: Engineering, Victoria County History of Lancashire, vol. II. (London, 1908).

Jeans, W.T. Creators of the Age of Steel. (London, 1884).

Jefferys, J.B. The Story of the Engineers. (London, 1946).

Johnson, W. The Imperial Cyclopaedia of Machinery (Glasgow, Edinburgh and London, 1852-6).

Kerr, J. Engineering at the Glasgow Exhibition. Engineering Magazine, vol. XXI, 1901.

Kimball, Dexter S. The Development of Machine Tools, Mechanical Engineering, 45, 1923.

Lea, F.C. A Pioneer of Mechanical Engineering: Sir Joseph Whitworth. (London, 1946).

Liddell Hart, B.H. Armed Forces and the Art of War. ch. XII of Bury, J.P.T. (ed.), New Cambridge Modern History, vol. X. (Cambridge, 1960).

Lincoln, Jonathan T. Machine Tool Beginnings, American Machinist, vol. 76., Aug. 3, 1932.

Love, B. Handbook of Manchester. (Manchester, 1842).

Lukin, Rev. J. Turning Lathes. (Colchester, 1899).

Lumb, A.E. A Catalogue of the James Nasmyth Collection in the Eccles Public Libraries. (Eccles, 1958).

McDougall, D. Machine Tool Output, 1861-1910. (Conference on Income and Wealth, 1963).

M'Laren, C.B.B. Machine Tool Production Engineering Supplement to The Times, Feb. 20, 1907.

MacGregor, D.H. Enterprise, Purpose and Profit. (Oxford, 1934).

Matschoss, C. (trans. H.S. Hatfield) Great Engineers. (London, 1939).

Maudslay Society of Great Britain, Henry Maudslay and Maudslay Sons and Field. (London, 1949).

Meysey-Thompson, A.H. The History of Engineering in Leeds. P.I.M.E., Aug. 1882.

Miller, F.J. American and other Machinery Abroad. American Machinist, American edition, vol. 20, May 20, 1897 and subsequent numbers.

Morgan, B.H. Report on the Engineering Trades of South Africa. (London, 1902)

Bosely Industrial Commission, Reports of the Delegates. (Manchester, 1903).

Musson, A.E. James Nasmyth and the Early Growth of Mechanical Engineering, Econ. H.R., vol. X, 1957.

Musson, A.E. Joseph Whitworth, Engineering Heritage. (Inst. of Mechanical Engineers, London, 1963).

Nicholson, J.S. The Effect of Machinery on Labour. (Cambridge, 1878).

Orcutt, H.F.L. Machine Shop Management in Europe and America. Engineering Magazine, vol. 17, 1899.

Page, W. Commerce and Industry, (London, 1919).

Parsons, R.H. History of the Institution of Mechanical Engineers. (London, 1947).

Payne, P.L. The Emergence of the Large-scale Company in Great Britain, 1870-1914. Econ. H.R., vol. XX, 3, Dec. 1967.

Perlee, B.H. Innovation in the Machine Tool Industry: Comment. Q.J.E., vol. 77, 1963.

Perrige, C.O.E. Modern American Lathe Practice. (New York and London, 1907).

Pole, W. (ed.) Life of Sir William Fairbairn. (London, 1877).

Pollard, S. Real Earnings in Sheffield, 1851-1914. Yorks. Bull. 1957.

Pollard, S. Wages and Earnings in the Sheffield Trades, 1851-1914. Yorks. Bull., 1954.

Porter, C.T. Reminiscences of Life as an Engineer. (New York and London, 1908).

Presser, R.B. Birmingham Inventors and Inventions. (Birmingham, 1881).

Rankine, W.J.M. Cyclopaedia of Machine and Hand Tools. (London 1869).

Ransome, J. Wages in the Engineering Trade. Engineer, LXXI. 3.4.1896, p.335, and 8.5.1896, p.457.

Reid, S.J. Sir Richard Tangye. (London, 1908).

Richard, J. La Mecanique a l'Exposition de 1900 (Paris, 1902).

Richard, G. Traite des Machines-Outils (Paris, 1895).

Richards, J. Machine Tools, American Machinist, 23, May 4, 1899, p.379.

Riddell, W.J. The Thankless Years. (London and Glasgow, 1948).

Rigby, John, The Manufacture of Small Arms. Engineering, May 26, 1893.

Robertson, H.M. Changing Production of Metal-working Machinery, 1860-1920. Conference on Research in Income and Wealth, 1963.

Roe, J.W. English and American Tool Builders. (New Haven, Conn., 1916).

Roe, J.W. and Lytle, C.W. Factory Equipment. (Scranton, Penn., 1935).

Rohan, J. Yankee Arms Maker. (London and New York, 1935).

Rolt, L.T.C. The Mechanicals. (London, 1967).

Rolt, L.T.C. Tools for the Job. (London, 1965).

Rose, J. Modern Machine Shop Practice. (London, 1906-7).

Rosenberg, N. (ed.) The American System of Manufactures. (Edinburgh, 1969).

Rosenberg, N. Technological Change in the Machine Tool Industry, 1840-1910. Journal of Econ. Hist., vol. XXIII, Dec. 1963.

Rousiers, P. de. The Labour Question in Britain. (London and New York, 1896).

Shadwell, Dr. A. Machine Tools, Engineering Supplement to The Times, 5.2.1908, 19.2.1908, 4.3.1908.

Slater, W.E.G. Productivity and Technical Change. (Cambridge, 1966).

Saul, S.B. The American Impact upon British Industry. Business History, vol. III.

Saul, S.B. The Machine Tool Industry in Britain to 1914. Business History, vol. X, 1, Jan. 1968.

Saul, S.B. The Engineering Industry, in Alderoft, D.H. (ed.) British Industry and Foreign Competition, 1870-1914. (London, 1968).

Saul, S.B. The Market and the Development of the Mechanical Engineering Industries in Britain, 1860-1914. Econ. H.R. vol. XX, 1, April, 1967.

Saul, S.B. The Motor Industry in Great Britain before 1914., Business History, 1961.

Sawyer, J. The Social Basis of the American System of Manufacturing. Journal of Econ. Hist., 1954.

Schlesinger, Dr. G. Die Stellung der deutschen Werkzeugmaschinen auf den Weltmarkte, Zeitschrift des Vereines dutschen Ingenieuras, 9.12.1911.

Schloss, D.F. Methods of Industrial Remuneration, (London, 1892).

Sellers, C. American Supremacy in Applied Mechanics, Engineering Magazine, vol. 2, 1891-2.

Sellers, M. Industries: Iron and Hardware, in Victoria County History of Yorkshire, vol. II. (London, 1912).

Shaw, F.W. Machine Tool Making in Halifax, England. American Machinist, American Edition, vol. 26, Sept. 21, 1903.

Shaw T.R. Lathes, Screw Machines, Boring and Turning Mills. (Manchester, 1903).

Shaw T.R. Machine Tools: Design and Construction. (Manchester, 1905).

Siddors, P.A. Machine Tool Building in Britain :
2. William Asquith Ltd., Highroad Well Works, Halifax, Machinery, Nov. 22, 1961.
4. Thomas Ryder and Sons Ltd., Turner Bridge Bolton, Machinery, Dec. 27, 1961.
5. David Brown Industries, Trafford Park, Manchester, Machinery, Feb. 21, 1962.
7. George Richards and Co. Ltd., Broadheath, Cheshire, Machinery, Mar. 28, 1962.

...er, R.A. Machine Tool Building in Britain:
...Prof... Pollard and ... Corona Works, Leicester, ..., April 11, 1961.
... James Archdale and ... Ltd., Blackpole, Worcester, Machinery, April 25, 1963.

10. Coventry Gauge and Tool Co. ..., ... Head Library, Coventry, ..., June 6, ...
11. H... Kearns and ..., ..., ... 4, 19...
... Drummond Brothers ..., Guildford, Machinery, ... 1, 1962.
... Herbert Engineering ... Ltd., Peterborough, Machinery Nov. 22d, 1962.
... ... Jones and Shipman ...td., Leicester, Machinery, ... 22, 1964.
... Churchill-Redman ...td., Halifax, Machinery, July 22, 1964.
... Giddings and Lewis-Fraser, Ltd., Arbroath, Scotland, Machinery, Nov. 11, 1965.
W... ... Parkinson and ... Shipley) ..., Shipley, Yor... Machinery, Dec. 17, 1...
... ...-Bisholt Machine Co. Ltd., Johnstone, Machinery, ... 22, 1962.

Smiles, ... Autobiography of James Nasmyth. (London, 1885)

Smith, ... Industries of Derbyshire, 1...-1960, in ... (No ..., ...).

Smith, S... A Short History of ... Machine Tools, (Coventry, 1...).

Smith, ...N. Cutting Tools Worked by Hand and ... (London, 1934).

...t, ... Paris, On Some Modern Systems of Cutting Metals, ..., April 1...3.

Solt..., James ... Origins of Small Business Metal Fabricators and Machinery Makers in New England, 1890-1957, Transactions of the American Philosophical Society, New Series, ..., Part 10, 1965.

Spic..., ... British Engineering Wages. (London, ...).

...on's Dictionary of Engineering, (London, 1873) and ... Management, (London, 1879).

Spon's [illegible] ook ([illegible], [illegible]).

[illegible]eds, . [illegible]tory o[illegible] ine Tools, 17[illegible]-1[illegible]10, (Oxford, 196[illegible]).

[illegible]tur[illegible], . The [illegible]ngineering Trade, in Halifax Commercial Year [illegible], ([illegible]alifax, 19[illegible]).

[illegible]trass[illegible], . [illegible] [illegible]logical Innovation.

[illegible]windell[illegible], T. [illegible]nches[illegible] [illegible]gts and [illegible]anchester [illegible]en. ([illegible] [illegible]ber, 190[illegible]).

Tangye, Sir Richard, The Rise of a Great Industry, (London, 1905).

, ... The ffects of the Automobile Industry on the Midland[illegible] [illegible], 1927.

Timmins, . ([illegible]) [illegible] Sources, Products and [illegible]trial [illegible]tory of Birmingham and the Midlands Hardware District ([illegible], 1966).

Tripp, . . [illegible]ool Chains. ([illegible], 1956).

Tupling, [illegible]. The Early Metal Trades and the Beginn[illegible] of [illegible]ineering in Lancashire, Proceedings of the [illegible]-ire and Cheshire Antiquarian Society, vol. [illegible], [illegible].

Van [illegible]ervoort, . . [illegible], (New York, 1911).

[illegible]ood, ... [illegible]ri[illegible] [illegible]ation, ([illegible], 1975).

Woules, [illegible].P. and . . [illegible] for Power, (London, [illegible]).

Wagoner, [illegible]. . The U.S. Machine Tool Industry from [illegible] to 1950, (Cambridge, Mass., 196[illegible]).

Walker, . . Startin[illegible] in Engineering Busine[illegible], Articles in The Practical Engineer, vol. 35, 1[illegible]-[illegible], [illegible]-June, 1[illegible]7.

Waterhouse, Ruth, [illegible] Makers of Engineering Craftsmanship: (A history of Tangye's). (Birmingham, 19[illegible]7).

Webb, Henry, English and [illegible]erican Methods in the Engineering and Iron [illegible]. Engineer, vol. 35, 21st January, 189[illegible].

Weissenborn, . _____ erican Engineering, (New York, 1861).

Williams, . _____ ance of Modern Mechanism, (London, 190).

Willis, Rev. . Machines and Tools for working in t l, ood and other terial, c . VIII of Lectures on the Results of the Great Exhibition of 1851, (London, 1852).

Wilson, G.H. and ____ or, . _____ en and achines: A History of . Napier ____ on, ____ ineers, Ltd., 1808-1958, (London, 1958).

Woodbury, . . _____ the Gear-Cutting Machine, (Cambridge, ass., 1953).

Woodbury, . . _____ the Grinding achine, (Cambridge, ass., 1959).

Woodbury, R.S. _____ of the Lathe to 1850, (Cambridge, Mass., 1961).

Woodbury, R.S. _____ y of the Milling achine, (Cambridge, ass., 1960).

Woodworth, J.V. _____ can Wood ____ ing and Interchangeable anufacture, (London, 1905).

____, . . _____ of the ____ trial _____, . . thesis, University of Birmingham, (Unpublished).

I. Government and Official Publications.

1. British.

Official Descriptive and Illustrative Catalogue of the Great Exhibition of All Nations, 1851. Edited by R.A. Ellis, (London, 1851).

Reports of the Commissioners of the Exhibition of 1851. First Report. .... 1852, xxvi, 1.

Report of R. Ellis and J. Whitworth on the New York Exhibition of 1853. P.P. 1854, xxxvi, 1 and 103.

Report of the British Commissioners to the Paris Universal Exhibition of 1855. P.P. 1856, xxxvi, Pts. I and II.

Reports of the British Commissioners to the Paris Exhibition of 1867. P.P. 1867-8, xxx, Pts. I and II.

Reports of the British Commissioners on the Vienna Exhibition of 1873. P.P. 1874, lxxiii, 1.

Education Department: Reports on the Philadelphia International Exhibition of 1876. P.P. 1877, xxxiv, 1; xxxv, 1; xxxvi, 1.

Reports of the British Commissioners to the Paris Universal Exhibition of 1878. P.P. 1880, xxxii, 1.

Report of the Royal Commission for the Australian International Exhibitions. P.P. 1882, xxviii, 1.

Official and Descriptive Catalogue of the Engineering and Metal Trades Exhibition, London, 1883. (London, 1883).

Select Committee on the Rating of Machinery, etc. Report. P.P. 1887, xi, 769.

Report of the Committee on the Organisation and Administration of the Manufacturing Departments of the Army. P.P. 1887, xiv, 1. (The Morley Committee).

Report of the Royal Commission to the Exhibition at Adelaide, 1887. P.P. 1888, xxiv, 1.

Census of Production, 1907. Part II, including Engineering Factories, P.P. 1910, cix, 155. Final Report, P.P. 1912-3, cix, 1.

Report of the Board of Trade, Exhibitions Branch, on the Argentine Centennial Exhibitions, Buenos Aires, 1910. ... 1911, xxi, 813.

Report of the British Commissioners to the Exhibition at Brussels, Rome and Turin, 1910-11. ... 1912-13, xxii, 1.

Report of the Engineering (New Industries) Committee of the Ministry of Reconstruction. ... 1918, viii, 633.

Report of the Committee appointed to consider the position of the Engineering Trades after the War. ... 1918, xiii, 369.

History of the Ministry of Munitions. (London, 1921-2).

2. Foreign.

Direction des Douanes et Droits. Commerce de la France. (Paris, annually).

Report of the United States Commissioners to the Paris Universal Exposition, 1867. (Secretary of State, Washington, 1870)

Report of the United States Commissioners to the International Exhibition held at Vienna, 1873. (Secretary of State, Washington, 1876).

Report of the United States Commissioners to the Paris Exposition of 1878. (Executive Documents, House of Representatives, 50th. Congress, 3rd. session, 1880).

Report of the United States Commissioners to the Paris Exposition of 1889. (Executive Documents, House of Representatives, 1889-90, vol. 40, 1893).

Official Description of the Paris Exhibition of 1889. (Paris, 1890).

Report of Consul Monaghan, Chemnitz. 10th January, 1897. United States Consular Reports, vol. lvi, Jan. 1897, p.91.

Report from U.S. Consul Halstead, Birmingham. February 1896. United States Consular Reports, lix, 221, p.245.

A. Works on the History of Machine Tool Technology.
(These books and articles are also listed under other sections of the bibliography, but are collected here for ease of reference.)

Atkinson, L.T. Machine Tools in 1847, Engineering, 163, June 1947.

Calloway, J.F. Machine Tools, chapter 26 of The Oxford History of Technology, vol. V., (Oxford, 1958).

Gilbert, K.R. The Science Museum: The Machine Tool Collection (H.M.S.O., London, 1966).

Gilbert, K.R. Machine Tools, chapter 14, of The Oxford History of Technology, vol. IV, (Oxford, 1958).

Moe, J.W. English and American Tool Builders. (New Haven, Conn., 1916.)

Holt, L.T.C. The Mechanicals (London, 1967).

Holt, L.T.C. Tools for the Job (London, 1965).

Smiles, S. Industrial Biography: Iron Workers and Tool Makers (London, 1863).

Steeds, W. History of Machine Tools, 1700-1910. (Oxford, 1969).

Woodbury, R.S. History of the Gear-Cutting Machine (Cambridge, Mass., 1958).

Woodbury, R.S. History of the Grinding Machine (Cambridge, Mass, 1959).

Woodbury, R.S. History of the Lathe to 1850 (Cambridge, Mass., 1961).

Woodbury, R.S. History of the Milling Machine (Cambridge, Mass., 1960).