University of
Bedfordshire

Title   Relating Practice to Performance

            A Study of Investment and Technology in UK

            Manufacturing Industry

Name   Xiaohong Li

RELATING PRACTICE TO PERFORMANCE

-A Study of Investment and Technology in UK Manufacturing Industry

by

XIAOHONG LI

A thesis submitted for the degree of Doctor of Philosophy of the
University of Luton

Dept. of Finance, Systems and Operations
Luton Business School
University of Luton
Park Square
Luton
LU1 3JU

May 2000

ABSTRACT

This study has quantitatively explored the relationships between investment, the use of technology and manufacturing performance in UK manufacturing industry from 1979 to 1995. The exploration of the relationships is based on the review and the meta-analysis of manufacturing practice and performance relationships in the past along with the related theories and economic factors.

The review of the operational management theory and the economic factors, which may influence manufacturing performance and practice relationship, helps to establish the wide context for this research and also contributes to the identified gaps. The meta-analysis of the relationships between practice and performance in the published studies has also contributed to the identified gaps in this research area. After the consideration of the discovered gaps and the availability of the database, the relationship between investment, the use of technology and manufacturing performance has been explored in this research.

In order to quantitatively evaluate the relationships between investment, the use of technology, their interaction and manufacturing performance, econometric modelling techniques have been used as methodological approaches. Two types of methods have been developed based on the review of the econometric techniques used in the past and the exploration of relevant econometric literature.

The first method uses multiplicative interaction regression models combined with the centralisation method and ordinary least square estimation technique to investigate the relationship between investment, technology usage and their interaction and one dimensional performance. The second method employs multiple-output models using the maximum correlation estimation technique to investigate the relationships between investment, technology usage and their interaction and two dimensional performance measures. A UK manufacturing database including two time periods, the 1980s and the early 1990s, covering seventeen years has been used to test the hypothesised relationships between investment in several forms, technology usage, their interaction and financial performance.

The research discovers that it was difficult for investment to bring benefits for performance improvement at the year of investment. The results support the hypotheses that a long-term planned investment brought benefits for manufacturing companies in the 1980s, however was not the case in the early 1990s. Technology usage was very important for performance improvement in the 1980s but the benefits brought by technology were diminishing as the mature stage of some key technologies was reached in the early 1990s. The analysis of the data suggests that the economic recession in the early 1990s was an important factor in explaining the phenomena and other economic factors might play a role as well. Investment and technology did interact with each other to contribute to performance improvement but it was not always the case. The results of the multiple-outputs model support the hypothesis that profitability and growth were two joint products of investment, the use of technology and their interaction in the immediate year or two after investment. This research also demonstrates the values of multiplicative interaction regression modelling and multiple-outputs modelling for manufacturing relationship studies.

ACKNOWLEDGEMENT

List of Figures **Pages**

Chapter 1   Introduction

1.1   Introduction

Nowadays, manufacturing companies world wide face the need to improve their performance in order to retain competitiveness. The urgency for UK manufacturing industry has been affirmed from both public reports and academic research. It has been recognised that some UK manufacturing sectors, such as the automobile industry and clothing industry, have been gradually taken over either in their production plants or their market shares by their foreign competitors. The study by Kitson and Michie (1996) stated that UK manufacturing was in decline. This was based on a comparison between the UK industrial performance and four other major industrial countries.

Therefore, there is a need to pursue that which can bring benefits to manufacturing companies' performance improvement, especially for those based in the UK. This can be conducted by exploring manufacturing practices and related factors, internal or external to firms, to identify those that enhance manufacturing companies' performance. This leads to widely investigate the relationships between manufacturing practice and performance using a UK manufacturing database and theories behind it. Studying the relationships between practice and performance not only draws attention to good practices but also takes into account the effects of the practices on manufacturing performance. The literature in the area of manufacturing practice and performance relationships reveals that, on the one hand, there are insufficient studies on the manufacturing practice and performance relationships, on the other hand, the studies which have explored the relationships between practice and performance provide different and sometimes contradictory findings.

Historical studies in this area can offer decision support by identifying the existence of past practice-performance relationships within organisations, which may be extrapolated to inform current decisions. Management decision making

can be enhanced by basing it on either the experience or the information provided by systematic studies in a similar situation in the past, or both. In order to improve the quality of management decision making in the future, understanding the past is necessary. This can be conducted through clarifying, investigating and examining the relationships between practice and performance in the past so as to provide a useful reference for today's manufacturing companies (especially UK companies) to improve their performance in the future.

In addition, the range of methodologies used in previous relationship studies is perceived as weak, especially on the quantitative estimations of the sizes of relationships. Substantially more rigorous conclusions can be generated if improved methodologies can be developed or more choices of methods are available for quantitatively studying manufacturing practice and performance relationships. The source for developing the methodologies in this study is mainly from the econometrics and multivariate analysis literature, although an investigation of the methods used in previous studies also contribute to methodology development.

In this chapter, the following aspects are covered:

1. The research aim and the objectives
2. The outline of the research methodology
3. The structure of the thesis

1.2   The Aim and the Objectives

The aim of this research is to develop suitable methods which can be used as a means to test the hypothesised relationships between performance and practice in order to provide the verified relationships to assist the UK manufacturing companies to improve some aspects of their performance.

The objectives, established to ensure the achievement of the aim, are as follows:

1. Reviewing the operational management theory related to the manufacturing practice and performance relationships, economic factors which provide a wide context on which the manufacturing relationships are based, manufacturing practice factors, and firm performance measures and measurement systems

2. Clarifying the relationships between practice and performance in manufacturing domain which have been studied in the past

3. Reviewing the methods that have been employed in the previous manufacturing practice and performance relationship studies

4. Discovering the gaps in the relationship studies and establishing the hypotheses

5. Developing suitable method(s) to quantitatively study the manufacturing relationships between practice and performance

6. Providing a reference on the hypothesised relationships to assist the UK manufacturing companies' performance improvement in certain respects.

1.3   The Outline of Research Methodology

The outline of this research along with the associations among its components can be described by figure 1.

**The Operational Management and Economic Theory
and Published Empirical Studies**

Literature Review

| A | B | C | D | E |

Theory &   **Practice**   **Performance**   **Studied**   **Used**   **Econometric &**
Economic   **Factors**   **Variables**   **Relationships**   **Methods**   **Multivariate**
Factors   **or Systems**   **Techniques**

F Meta-Analysis

**Clarified
Relationships**

H

G
Possible Relationships   **A UK Company's
Database**

I
Hypotheses   **Suitable
Processes**

J
Tested Hypotheses

K

Interpretation, Discussions and Conclusions

Figure 1.1   **The Outline of the Context of this Research**

The outline of this research illustrates the entire process of the methodology
employed in this research. The process includes eleven parts and each part is
coded using an alphabetical letter, which is from A to K. There are two main lines
carried on in parallel during the literature review before the hypotheses
constructed. The first line of the literature review includes four parts. One part is
the review of operational management and economic theory and economic or
external factors (A), which provides a wider context, in which the manufacturing

performance and practice are grounded. One is the review of practice factors in empirical studies (B). The third one is the review of performance variables and performance measurement systems (C). The relationships studied in empirical studies in the past are reviewed in the fourth part (D). Further to the fourth part, the meta-analysis is applied to generate clarified relationships (F). The other line is the review of the methods (E) that have been employed in these relationship studies. The first line of the review generates the possible relationships (G), which are desirable for further exploration. The second line of the review contributes to the development of methods. However, it is not appropriate to develop suitable methods until the hypotheses have been established and relevant econometric models have been explored.

The characteristic of this research is to *quantitatively* evaluate the hypothesised relationships using developed models. This requires an adequate size of sample in both dimensions, cross-section and time series at least for some variables. A UK longitudinal and cross-sectional manufacturing database was initially available for ten years and is extended by this research into another seven years. This long period database verifies the possibility of conducting this research.

Therefore, the hypotheses are constructed based on two constraints (I). One is the possible relationships that form the gaps in the manufacturing relationships studied so far and the other one is the availability of the variables in the database. It is impossible to explore all the possible relationships proposed at the early stage of this research in detail. After considering the availability of the database in hand, the relationships between investment, the use of technology and manufacturing performance are chosen for further exploration. Hence, the hypotheses of this research are constructed based on these relationships.

Two types of models (single performance variable and multiple-performance variables) are developed to test the hypotheses (H). Along with these models, the related estimating techniques are also developed based on the review of the used methods and the exploration of relevant econometrics and multivariate analysis

techniques. *Models* and estimating *techniques* are combined to form the developed *methods*. Consequently, the established hypotheses can be tested using the database applied in the developed methods (J). The results generated inform not only the specific relationships but also the development of the methods which can be used for relationship studies in the domain of manufacturing practice and performance relationship studies. The results of modelling is interpreted and discussed in the light of the reviewed theories and economic factors (K).

Process A fulfils objective 1. Processes B, C, D and F satisfy objective 2. Process E is used to complete objective 3. Objective 4 is completed by process G and I. Objectives 5 is gained by process H. Lastly, process J and K attain objective 6.

1.4   The Structure of the Thesis

In order to realise the research objectives and therefore achieve the aim, the eight chapters have been arranged in this thesis. Figure 1.2 illustrates the contents of these eight chapters and the basic relationships between them.

```
                        ┌─────────────────────┐
                        │   1-Introduction    │
                        └─────────────────────┘
                             │            │
          ┌──────────────────┘            │
          ▼                               │
┌──────────────────────────┐             │
│ 2-Literature review of   │             │
│ economic and operational │             │
│ management theory and    │             ▼
│ empirical studies        │   ┌──────────────────────────┐
│ related to the           │   │ 4-Review of the          │
│ manufacturing practice   │   │ quantitative research    │
│ and performance          │   │ methods                  │
│ relationships            │   └──────────────────────────┘
└──────────────────────────┘             │
          │                              │
          ▼                              │
┌──────────────────────────┐            │
│ 3-The meta-analysis of   │            │
│ the relationships        │            │
└──────────────────────────┘            │
          │                             │
          ▼                             ▼
       ┌────────────────────────────────────┐
       │ 5-Research issues and              │
       │ methodological approaches          │
       └────────────────────────────────────┘
                      │
                      ▼
       ┌────────────────────────────────────┐
       │ 6-Developing methods and applying  │
       │ them                               │
       └────────────────────────────────────┘
                      │
                      ▼
       ┌────────────────────────────────────┐
       │ 7-Results and interpretations      │
       └────────────────────────────────────┘
                      │
                      ▼
       ┌────────────────────────────────────┐
       │ 8-Discussions and conclusions      │
       └────────────────────────────────────┘
```

Figure 1.2   The Illustration of the Basic Structure of the Thesis

Following this introduction for the whole research, a review of the operational management and economic theory along with performance variables and measurement systems, practice factors, and their relationships that have been studied in the manufacturing field is conducted in chapter 2. Chapter 3 presents meta-analysis methodology, which is used to clarify the different findings of the relationships, and its application and the results of the meta-analysis on the relationships between manufacturing practice and performance. In chapter 4, the methods that have been employed to explore the sizes of the relationships between manufacturing practice and performance are reviewed, with the support of basic knowledge related to these methods. Chapter 5 exposes research issues and

methodological approaches, which include presenting the gaps discovered in the previous chapters, describing the sample, developing and establishing the hypotheses, and providing methodological approaches which can be employed to undertake the hypotheses. The two types of methods have been developed to test the constructed hypotheses in chapter 6. Chapter 7 provides the results of the modelling using developed methods and presents the findings and the interpretations related to hypotheses in two sections – one for each developed method. Discussions and conclusions for this research are drawn from the findings, in the light of the reviewed theory and external/ economic factors' influences in chapter 8. The structure of chapter 8 is arranged in line of the research objectives with emphasis on the hypothesised relationships and the developed methodologies for studying manufacturing practice and performance relationships in future, and recommendations for further research are provided in this chapter as well.

Chapter 2 Literature Review

2.1   Introduction

This research focus on manufacturing practice and performance relationship studies, which have been constructed into the aim and the objectives presented in the introduction chapter. In the literature, there are no accepted definitions of performance and practice because these two concepts depend very much upon the area on which the research is based. In general, practice is viewed as a pattern of management action and performance refers to the achievements of the organisation or individuals. In this research, performance and practice are studied in the manufacturing context. Hence they refer to achievements and management actions in manufacturing companies and industry.

Performance measures employed in a company reflect the perspectives from which the company perceives its outcomes. There is a rich vein of literature on performance measurement issues and there are also some studies discovered on best practices in the manufacturing context. It forms a foundation for manufacturing practice and performance relationship studies. Compared with performance measurement and best practice literature, the research on the relationships between these two factors is less extensive. However, the literature review up to 1995 discovered 45 manufacturing performance and practice relationship studies (appendix 1). These studies employed diverse performance variables and practice factors.

The first objective of this research is to review the operational theory related to the manufacturing practice and performance relationships, economic factors, manufacturing practices and firm performance measures and systems. Then, the manufacturing practice and performance relationships can be clarified next, identified at the second objective. The focus of the first objective is on the factors influencing firm performance. In order to do so, theoretical works on practice factors, whether they are internal or external to firms, and the economic and environmental context of the firms, need to be reviewed first to obtain a whole

picture and theoretical foundation for further studying their effects on firm performance.

In order to conduct the second objective, it is necessary to review and classify the performance variables and the practice factors that have been used in the manufacturing practice and performance relationship studies. Besides the 45 studies, studies of either performance measurements or best practices issues have also contributed to the construction of possible performance variables and practice factors. It is impossible to cover all performance and practice variables researched in the past. The variables used in these 45 studies are covered in this research.

Furthermore, performance variables, practice factors and their relationships in published empirical research are reviewed and explored to draw out the substance of this research.

Therefore, this chapter reviews the following aspects:

1. Theoretical work on factors influencing performance
2. Performance variables and measurement systems and approaches on theoretical and empirical grounds
3. Practice factors generated from empirical studies
4. The relationships between manufacturing practice and performance

2.2   Theoretical Work on Factors Influencing Performance

In this section, factors influencing performance from different perspectives and disciplines are reviewed and compared. After general review of these factors studied from different perspectives, the focus of the section is on the economic literature and operational management literature, which provides theoretical work on factors influencing performance externally and internally.

External factors and economic performance at the national level (macro-economy) and the British economy are large research domains which are outside the stated scope of this research, constrained by the aim and the objectives identified in the

introduction chapter. However, the understanding and awareness of these external factors and the British economy during this time period help interpretation and analysis of the relationships between manufacturing practices and firm performance to gain a more objective and deeper perspective.

2.2.1   The Different Research Scopes and Perspectives between Economics and Management Science on the Factors Impacting on Performance

The factors influencing manufacturing performance can be either internal or external to a firm. Manufacturing practices at the firm level are internal factors to a firm, such as lean production, new product development. These internal factors are mostly controllable by the firm. In addition to these internal factors, there are kinds of external factors that are also relevant to firm performance. These factors are mostly uncontrollable by manufacturing firms and they may have direct or indirect impact on firm performance.

External factors can be either at the manufacturing industry level, such as industrial characteristics and market structure, or at the national level, such as government policies, environmental and economic factors. Internal factors are at the firm level. Understanding these external factors and their effects on performance ensures a more sophisticated interpretation of the internal factors and their effects on firm performance, which are the relationships between manufacturing practices and firm performance, the focus of this study.
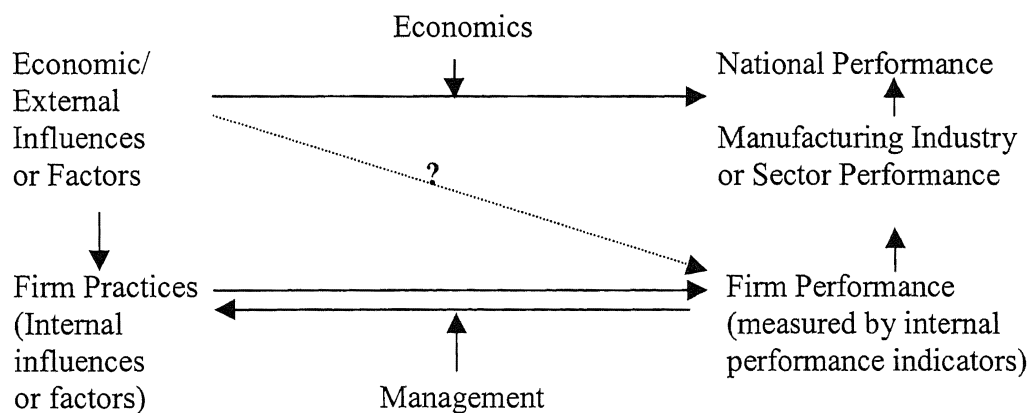
Figure 2.1   The Relationships between Internal and External Factors and Performance at Three Levels

Figure 2.1 provides a general picture of areas which are researched in economics and management and the three levels of performance and practices related. In economics, researchers focus their research primarily on industry or national performance rather than firm performance, except, perhaps, for the economists who study the resource-based theory, which is based on firms. Management researchers focus their studies on best practices at the firm level and firm performance measurement systems and also the relationships between them.

Few recent empirical studies have researched the direct influence of economic/external factors on firm level performance, an exception being Hansen and Wernerfelt (1989) which investigated industrial characteristics and its direct effect on firm performance. Is the literature at this perspective missing, or simply, do most of these external factors have to moderate other internal factors to influence firm performance?

The effect of industry factors on inter-firm financial performance has been studied by Powell (1996). He concluded that about 20 percent of inter-firm financial performance variability is explained by industry factors, defined as industry maturity, entry barriers, and competitive power. This research is based on a survey of 166 USA companies. Therefore, its application may be limited. However, the findings of this survey by Powell (1996) supported earlier findings based upon empirical studies using Federal Trade Commission Line of Business data which suggested that 17 to 20 percent of financial performance variance among firms can be explained by industry membership (Schmalansee, 1985; Wernerfelt & Montgomery, 1988 and Rumelt, 1991).

Thus more than 80 percent of variability will be explained by other factors. Rumelt (1991) addressed this point and concluded that "…stable business-unit effects are six times more important than stable industry effect." (pg. 168).

Figure 2.1 also indicates that individual firm performance in a manufacturing sector or industry decides the sector or the industry performance. The

performance of manufacturing industries contributes to national performance. In addition, there are studies from marketing aspects which investigated non-industry specific determinants of superior performance mostly measured by market share, which are not described in figure 2.1.

At the firm level, the resource-based theory (Grant, 1998; Amit & Schoemaker, 1998 and Prahalad & Hamel, 1998) of the firm has redirected the focus of explaining organisational performance away from environmental variables and to company internal factors, their characteristics and the way in which they develop over time. In a wider context, the manufacturing practices can be viewed as resources, which, when integrated with financial resources, human resources and other physical resources, contribute to firm performance.

Furthermore, there are other perspectives related to this issue. For example, a firm performance can be achieved through the function of the balance between supply and demand. If demand is greater than supply, this tends to lead to high performance (Porter, 1998). This argument is based on the potential of the market can stimulate the goods production leading to full capacity of manufacturing resources and in turn to achieve high performance. In addition the unit value of goods, which is frequently a factor in the performance assessment, is the highest under these market conditions.

There are also arguments on what is more important to firm performance. Kay (1993, pg. vi) stated that "Economists have studied the functioning of industry, but their concerns were mostly with public policy, not business policy, and I was sure that industrial success was founded on the behaviour of firms, not on the decisions of governments. Sociologists had studied the functioning of organisations, but only a few had matched the characteristics of the firm to the economic environment that determined its competitive performance".

An example of the latter is by Hansen and Wernerfelt (1989), who developed a model that integrates economic perspectives and organisational perspectives in

business policy literature. They argued that in the business policy literature there were two major streams of research on the determinants of firm performance. One is based primarily upon on economic tradition, emphasising the importance of external market factors in determining firm success. The other line of research builds on the behavioural and sociological paradigm and sees organisational factors and their fit with the environment as the major determinants of success.

They stated that industrial organisation economics had proven extremely useful to researchers of strategy content in providing a basic theoretical perspective on the influence of market structure on firm strategy and performance. The major determinants (economic factors) of firm-level profitability identified in their research are:

(1) characteristics of the industry in which the firm competes (measured by industry growth, concentration, capital intensity and advertising intensity);

(2) the firm's position relative to its competitors (measured by relative market share); and

(3) the quality or quantity of the firm's resources (size of firm).

They used organisation structure, systems, and people for organisation factors. The modelling results indicated that the organisational factors explained about twice as much variance in firm profit rates as economic factors. They also concluded that "'good' organisational practices help a firm select a good economic environment, or obtain relative advantage through the creation of intangible or invisible assets" (Hansen and Wernerfelt, 1989, pg 408).
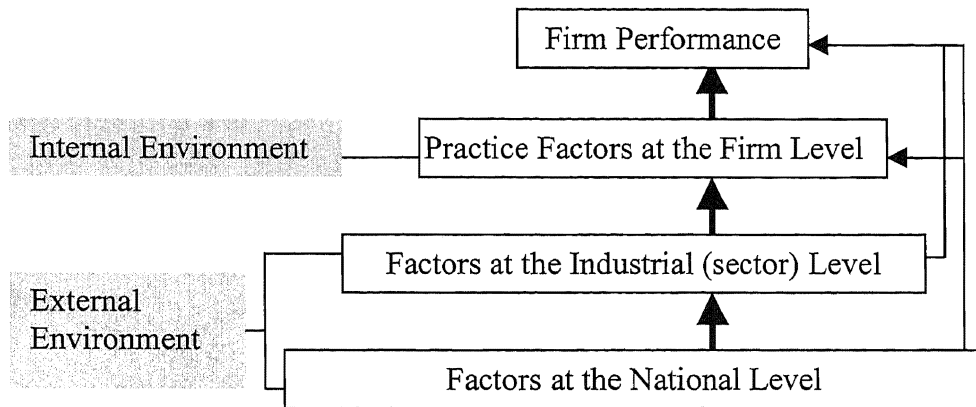
Figure 2.2   The Hierarchy of Relationships between Firm Performance and Factors at Three Levels, Firm, Industry and Nation.

Figure 2.2 provides an illustration on the relationships of factors on firm performance and the related environment. Internal factors are direct determinants of a firm's performance and external factors have to impact on internal factors to eventually influence a firm's performance (Kay, 1993). It cannot deny or neglect the functions or impacts of external factors on firm performance. These external (industrial or national) factors should be recognised to understand the firm performance changes or the relationships between internal factors and firm performance.

Therefore, figure 2.3 depicts possible internal practice factors and external or economic factors, which have direct or indirect influences on firm performance and the relationships between them.

Technological Changes
& Opportunities
at the Industrial and
National Levels

Industrial
Characteristics
and Structure

Government
Policies

Exchange
Rates

Interest Rates

Oil Prices

Other External
Factors

Age of firm

Technology

Unionisation

Export

Size of firm

Market Share

Planning

FMS

Investment

**Manufacturing
Firm Performance**

Cost reduction

New Product
Development
R&D

Quality

Human
Resource
Management

Other Internal
Factors

Diversification

Lean Production

Firm (internal) Environment

Market Structure

Industry Life Cycles
or Business Cycles

Economic or
Environmental
Stability

Economies
of Scale

Inflation

Growth/
Recession

Manufacturing
Investment
Incentives (total)

Economic (external) Environment

**Figure 2.3   A Framework of Internal and External Environment of Firm
Performance.**

This summary of the factors in figure 2.3 is based on theoretical work reviewed in
this area. The book edited by Healey (1996) from an economic point of view has
mainly contributed to the collection of the external factors, with contributions
from others (Stonier & Hague, 1972; Coombs, 1988 and Beardwell, 1996). The

internal factors are mainly from operational management science (Slack et al, 1995, and Galloway, 1993) and the relevant journal articles reviewed. The practice factors drawn from the published works in academic journals, which are mostly empirically based, some with theoretical development, are reviewed in greater detail in section 2.4.

Porter (1998) and Radder and Louw (1998) have identified external and internal factors from slightly different perspectives, not specifically from a performance improvement point of view. Porter (1998) identified external factors as industry structure and positioning (product market competition) and internal ones as core competencies, critical resources, which are crucial for companies to achieve competitive advantages. Looking from strategic decision-making perspectives, Radder and Louw (1998) identified the external factors as industry strength and environment stability and internal factors as competitive advantage and financial strength, using the Strategic Position and Action Evaluation (SPACE) Matrix method.

Radder and Louw (1998) also further identified the elements in each factor. The key elements which determine environmental stability include:
- technological change;
- rate of inflation;
- demand variability;
- price range of competing products;
- barriers to entry into the market;
- competitive pressure; and
- price elasticity of demand.

The elements determining industry strength include:
- growth and profit potential;
- financial stability;
- technological know-how;
- resource utilisation;

- capital intensity;

- ease of entry into the market; and

- productivity or capability utilisation.

Critical elements in competitive advantage are:

- market share;

- product quality;

- product life cycles; and

- product replacement cycles.

The elements influencing the financial strength include:

- return on investment;

- leverage;

- liquidity;

- capital required/available;

- ease of exit from the market; and

- the risk involved in business.

The two external factors and their elements have been included in figure 2.3. The elements of these two external factors are at a further detailed level. Most of the internal factors and elements of the factors have been mentioned in figure 2.3. Some specific elements listed above are not included in figure 2.3, such as product replacement cycles and ease of exit from the market. It is because they may also represent a dimension of a factor included (for example, the element of product replacement cycles is one dimension of NPD).

They stated "that successful strategies are based on an understanding of the macro environment, the industry and the organisation's (in our case manufacturing firms) internal environment" (Radder and Louw, 1998, pg. 549).

The next two sections further review and examine the external and internal factors and theories behind these factors (the functions of the factors and relationships

between them) in terms of performance improvement perspective.

2.2.2 External/Economic Factors Influencing Performance

The external factors depicted in figure 2.3 can be classified into three groups, the factors related to industry or at the industrial level, the factors related to government policies and essential economics, and the factors relevant to economic status of the nation. The economic factors mentioned in this section have been drawn, not only from the research concerning these factors' impacts on performance (mostly on state or industry economic performance), but also from relevant areas in which the economic factors have been mentioned.

The factors that are at the industrial level or measure industry status are:

1   industrial characteristics and structure;
2   industry life cycles or business cycles;
3   technology changes and opportunities at the industrial level;
4   market structure; and
5   economics of scale.

In the second group, the following factors are included:

1   government policies;
2   manufacturing investment incentives;
3   exchange rates;
4   interest rates; and
5   oil prices.

The third group includes:

1   total investment;
2   economic or environmental stability;
3   inflation; and
4   growth or recession.

Of course, there may be other factors that are relevant to performance. For example, technological changes and opportunities at the national level have not

been included in either group, even though they have influence on technological changes and opportunities at the industrial level and further may affect performance through the practices employed in manufacturing companies.

In the first group, the factors at the industrial level have been considered. The factors at the industrial level are more direct to firm performance than the factors in the other two groups. Researchers have also investigated these factors cumulated at theoretical level and applied them in practice related to firm performance. Hansen and Wernerfelt (1989) included industrial characteristics as one of the variables in their economic model. In industrial characteristics, they also used two marketing aspects, concentration and advertising intensity and other variables such as growth and capital intensity. They studied the impact of industrial characteristics on firm performance, which has been mentioned earlier.

Radder and Louw (1998) included technological change and inflation rate in their research as factors to determine environmental stability. Technological opportunities, industrial life cycles and industry structure have been studied by Coombs (1988). He has noticed the change in perception of technological opportunities, regarding the nature and significance of "technological opportunities", from particular innovations to the development of technologies more broadly. He focused his study on the connections between market structure and technological change rather than direct influence of technological opportunities on economic performance.

Uri (1988) has studied market structure (industry structure) and economic performance. He used three variables to represent market structure: concentration, advertising expenditure, and research and development outlays and investigated their interrelationship with profitability. Other variables have been included in each of four models using each of the variables as dependent variable. He discovered there were strong relationships between these factors but not in every single case.

The factors in the second and third groups have been studied both theoretically and empirically but with emphases on theory development at the macro-economic level and their impacts on industrial or national performance rather than on firm performance.

These external factors in the last two groups are strongly related. The factors in the second group are more or less causes of the factors in the third group. Government policies, such as, labour law, taxation, privatisation or nationalisation and other policies, can affect economic and environmental stability and control inflation rate either negatively or positively, sometimes cause economic recession or growth and possibly change economies of scale in the long run. Oil price is a good indicator for the economy (Maynard, 1993). Changes of interest rates can affect exchange rates and therefore influence manufacturing international trading and eventually affect the national economy.

During the period 1979 to the early 1990s, which is the period of data which this research investigates, Britain was led by the Conservative party. The economy was directed by Thatcherism rather than Keynesian. During this period, her policies were mainly fighting inflation using supply-side economic control by reducing taxation and implementing privatisation and tougher labour laws (Nolan, 1996). There are studies that investigated these issues. For example, Wright et al (1989, 1992) analysed the UK privatisation experience and the possible benefits, which privatisation might bring, with the comparison with the Government privatisation objectives. Wright et al (1992) also mentioned that the privatisation of UK was problematic using the Bus industry as a case. Suffering from the Northern sea oil crisis and under-investment along with high unemployment (Healey, 1993), the nation experienced two major recessions, one from 1979 to 1981 and the other one from 1990 to 1992. Manufacturing industry was hit particularly hard by the recession from 1979 to 1981 and did not regain its 1979 level of output until 1987. Total manufacturing investment more or less collapsed during the first half of the 1980s, and although it recovered somewhat in the latter half of the 1980s, it only returned briefly to the levels attained in 1979 before

falling again as the 1990-2 recession began to bite (Blackaby & Hunt, 1993). The real manufacturing investment in 1987, for example, was approximately one-tenth lower than in 1979 (Glyn, 1989). "Investment in new plant and equipment is essential for underpinning continuing productivity increases and it is clear that this investment was not taking place even in the 1980s; with the economy hit by the recession of 1990-2, levels of investment have fallen further still" (Blackaby & Hunt, 1993, pg. 123). Manufacturing industry was particularly hard hit by the government's use of high interest rates to 'squeeze out' the upsurge of inflation between 1988 and 1990.

From 1983 to 1988, the rate of inflation stayed in the range 3.5-6 per cent, the variation year to year of inflation being explained partly by exchange rate changes and partly by the fall in world oil prices in 1986. Until 1986, oil output in the North Sea was rising strongly and making a very useful contribution to the British economy, especially by improving the balance of payments and increasing government revenue. However, Britain entered the 1990s with inflation rising towards 10 per cent, higher unemployment and a less favourable external outlook. Also, oil output has levelled off, actually falling in 1988 and 1989 because of production difficulties. The level of oil production recovered somewhat in the early 1990s. During this period, the productivity (measured by total factor productivity calculated by output of per head employed) seemed high. However, due to very high unemployment (from 1 million to 3 millions), the actually productivity in this period was a false indicator of British economy. The relative improvement of the British economy compared with the 1970s, has been somewhat exaggerated by the measure. It is "since Britain's performance in this decade was, as for all other countries, adversely affected by oil price shocks which not only checked output growth, but also led to the substitution of labour and capital for energy and consequently to a decline in productivity" (Healey, 1993, page 61).

In this sub-section, economic or external factors to firms have been categorised into three groups. The effects of these factors on performance have been reviewed

with an outline of the British economy. In the next sub-section, internal factors to firms are reviewed based on theoretical work of the operational management science. envelop

2.2.3   Internal Factors/Manufacturing Practices Influencing Firm Performance

As we mentioned before, internal factors play important roles for improving manufacturing firm performance. These factors are direct influences on firm performance.

The operational management domain establishes theoretical knowledge and provides the context to manufacturing practices. Manufacturing practices established in the operational management are theoretically beneficial for improvement of firm performance. However, in reality, the research whether theoretically or empirically grounded has not been able to come to a firm conclusion on most of manufacturing practices. Coombs (1988) has experienced a similar issue by studying market structure and innovation. He stated "that the literature on the relationships between market structure, firm size and innovation is voluminous but has not been able to come to a firm conclusion"(pg. 296).

Both on theoretical and casual observation grounds studying the relationship between a practice and performance, it is easy to propose the advantages and disadvantages of each practice factor to firm performance. However, it is difficult to draw a universal conclusion on a single practice and bring it up to theoretical level. On the other hand, the operational management, which have been developed during management development and are still developing as the world is changing, have cumulated knowledge and experiences, which can be generalised to operational management theories. For example, the theoretical validity of total quality management practice has been established through the cumulated results of the implementation of it in companies. There are the studies that researched the best practice factors or the developed or improved performance measurement systems on theoretical grounds. However, these theories have to be consistently tested using empirical work to further develop the existent theories. Theory needs

empirical evidence. Sufficient empirical evidence cumulate the knowledge and eventually assist the establishment of theories.

Operational management (Slack, et al, 1995) has provided the context, which the manufacturing practices can be based on, with logical interpretations and explanation on how these practices work, with real world cases. It also illustrates the underlying principles of operations decisions. Slack et al (1995) stated that "operations management is a subject which should be based on practice, it cannot be taught satisfactorily in a purely theoretical manner."

The functions and context of operational management need to be understood first in order to investigate and interpret operational practices and also the links between them in the rich context of the subject. This study focuses on manufacturing practices with the intention of investigating the interactions or links between these practices and further their effects on firm performance. Therefore, the functions or practices of operational management are reviewed here. Because this study is based on manufacturing domain even though operational management is not just for manufacturing companies, the review on these functions is perceived from manufacturing perspectives.

Operational management mainly covers certain specific functions, and practices are generated or required or implemented in order to perform or improve these functions. In operational management literature, the operational functions are generally classified into operational strategy, operation design, planning and control and improvement (Slack et al, 1995). These parts are connected to each other to form the whole process in which operations of a firm are performed. Operational strategy is acting as a core of other functions and composes and directs the other parts of operational management functions in a manufacturing firm to ensure that the activities are performed in the way expected. Operational strategy determines the activities of operational management (Slack et al, 1995), or practices implemented in an organisation. The relationships between them can be illustrated by the following figure.
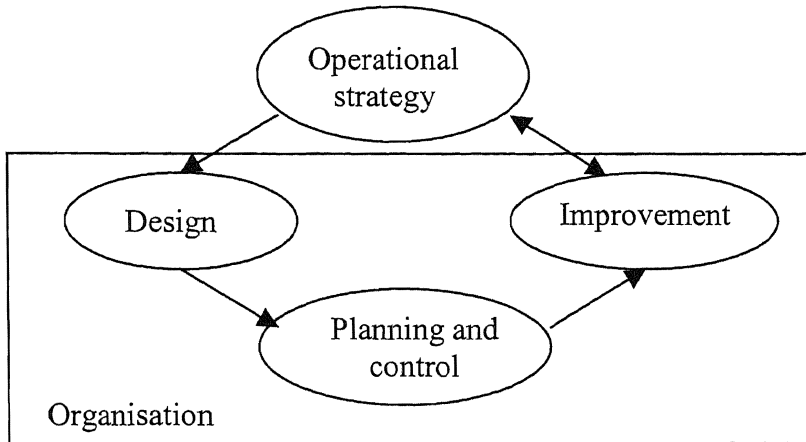
Figure 2.4   Operational Functions and their Relationships without Including External Environment

Figure 2.4 (after Slack et al, 1995, page 80) illustrates the direct functions of operations management and their basic relationships. Operational management has following direct responsibilities:

- Understanding the operation's strategic objectives;

- Developing an operations strategy for the organisation;

- Designing the operation's products, services and processes;

- Planning and controlling the operation; and

- Improving the performance of the operation.

The theoretical establishment of these contexts and relevant operational practices are reviewed as following.

Operational Strategy

A 'strategy' is the total pattern of the decisions and actions that position the organisation in its environment and are intended to achieve its long-term goals (Slack et al, 1995). A business unit's strategy is mostly built in a hierarchy, such as corporate strategy, business strategy and function strategy. At function strategy level, there are R&D strategy, marketing strategy, operational strategy, finance

strategy and human resources strategy (Slack et al, 1995, page 84). Operational strategy, which has direct relation to this research, includes strategies at both the micro level and macro level. On the one hand, the micro operational strategy should be devised only within the context of a well-defined macro operation strategy and support the macro strategy by considering each part of operations, and on the other hand, the macro strategy should direct the micro strategy. At the micro level, which is related to each part of the operations, many kinds of practices have to be implemented in order to realise the macro strategy and in turn to achieve company higher level strategy objectives.

Nowadays, in competitive environment, an organisation has to face the operational challenges to improve itself consistently to ensure survival and success. Operational challenges provide a pull power to encourage organisational performance improvement and further affect the strategy decisions of an organisation. In the theory, the operational challenges are based on strategic thinking and direction. There are the four challenges have to be considered in order to formulate effective operations strategies. They are *ethical* operational strategies, *international* dimension of operational strategies, *creativity* in devising operational strategies, and *implementing* the chosen strategies. These four challenges keep an organisation to carry on improvement and implementing effectively practices to ensure to achieve good performance.

A strategy has its own content. Operational strategy content is the collection of policies, plan and behaviours which the operation choose to pursue. In the content of operational strategy, the issues, related to the priority of its performance objectives, design decisions, planning and control decisions and improvement decisions (also see figure 2.4), have to be included and determined, because the strategy is the core of the other parts of operational functions in an organisation.

The questions related to the priority of its performance objectives, such as which performance objectives are particularly important, need to be considered and determined. For the issues related to design decisions, those questions concerning

the number, size and location of plants as well as the product/service design, layout, technology and human resources are relevant. The questions concerning capacity adjustment and the systems, which manage the delivery of products, are both related to planning and control decisions. The questions concerning the monitoring and improvement of the operation's performance clearly relate to improvement decisions.

Manufacturing practices are generated or implemented through functional departments, such as design, control and planning and improvement rather than in the direct context of operational strategy. Strategies should be guidelines of the functional departments. Therefore, manufacturing practices are not mentioned in this sub-section and are put forward in these following sections.

Design in Operational Management

Design in operational management has a wide context including product, service and process design.

At a more operational level, process design means the physical arrangement of the operation's facilities, technology and people. The following practices are relevant:

1. Investment-related to design products, services and processes

2. Research and development (R&D) and new product development activities
   Research and development expenditure as a percentage of sales is about 2.9% for manufacturing (Slack et al, 1995, page.163).

3. Cost "reduction"-related to design products, services and processes (value engineering, such as cost-to-function analyses)

4. Use of technology in design. Use of technology is a very important practice factor in design in operational management, particularly for manufacturing companies. These technologies can be classified into product technology,

service technology and process technology. In this study, the emphasis is on process technology rather than product/service technology, which are the technologies used to manage product/service functions. The technologies used in design and their benefits brought to the company are reviewed at theoretical basis.

Process technology are the machines, equipment and devices which help the operation to transform materials and information and customers in order to add value and fulfil the operation's strategic objectives. Process technology includes information processing technologies, materials processing technologies and customer processing technologies. Information processing technologies dominate other development processing technologies by managing and transferring information for other processing technologies (Slack et al, 1995).

Materials processing technology:
There are many kinds of materials processing technologies, which have been developed through time.

In the 1950s, a method of controlling the machine tools was developed. It is called computer numerically controlled (CNC) machines. This technology can give more accuracy, precision and repeatability of the process. It can also give better productivity, partly through the elimination of possible operator error, partly because computer control can work to optimum cutting patterns and partly of the substitution of expensive, scarce and/or skilled labour.

In the 1960s, Robots were first introduced for industrial applications. The technology using robots can be called 'Robotics' in general. Around the similar period, automated guided vehicles (AGVs) have been introduced, which are small independent powered vehicles, which move materials to and from value-adding operations.

Then, it came the time when flexibility manufacturing systems (FMS) was introduced. FMS brings together the technologies described above. FMS can be defined as a computer-controlled configuration of semi-independent work stations connected by automated material handling and machine loading (Voss, 1986). An FMS is more than a single technology as such. It has integrated single technologies into a system which has the potential to be greater than the sum of its parts. In effect an FMS is a self-contained 'micro operation' which is capable of manufacturing a whole component from start to finish. Furthermore, the flexibility of each of the individual technologies combine to make an FMS (at least in theory) a supremely versatile manufacturing technology (Slack et al, 1995).

It has been concluded at theoretical level that there are following benefits of using FMS (Bessant, 1991):

- Lead time and throughput (factory door-to-door) time reduction;
- Inventory savings (especially of work-in-progress);
- Increased utilisation;
- Reduced set-up times;
- Reduced number of machines or operations; and
- Increased quality.

Computer-integrated manufacturing (CIM) is one form of process technologies at higher level exemplified by FMS. Integrating FMS with other computer related technologies, such as CAD and Computer-aided manufacturing (CAM), can be understood as CIM.

A further integration of CIM and the computer-based systems of other functions, suppliers and customers can reach an even higher level of integration called computer- integrated enterprise (CIE).

Information processing technology

Information processing technologies include any devices which collect,

manipulate, store or distribute information. Most of these are classified under the general heading of 'computer-based technologies'.

Except for centralised and decentralised information processing to transfer information through the network system, management information systems (MIS) is an important information processing technology to change, manipulate and present information so it can be used in managing an organisation.

Customer processing technology

Traditionally, customer processing operations (e.g. hotels and hospitals) have been seen as 'low technology' when compared with materials processing operations. Technologies allowing customers to interact, directly or indirectly with staff can be viewed as customer processing technologies. However, there is minimal relevance to manufacturing organisations.

5. Quality Management-related to design in products, services and processes

6. Interactive design-merging the design of products/services and the processes, which create them, is sometimes called interactive design.

7. Job design-related to human resources management. Job design includes the activities which influence the relationship between people, the technology they use, and the work methods employed by the operation.

It can be seen that there is a wide range of manufacturing practice factors involved in operational design function in an organisation. These practices factors or activities have been developed and are beneficial theoretically to organisation operation and performance. Some of these practices are not only performing in the design function but also in other operational functions. However, the emphasis of these practices reviewed in operational design is on design.

Planning and control

Planning and control is concerned with operating resources on a day-to-day level in order to ensure that the operation runs effectively, performs properly and produces products and services as it should. There are practices involved in order to realise these planning and control's functions.

1. Capacity planning and control. The capacity of an operation is the maximum level of value-added activity over a period of time that the process can achieve under normal operation conditions. The activities or practices involved are measuring and planning capacity with consideration of demand and possible other activities related to capacity management.

2. Inventory management. It is one of the activities in planning and control with developed analysis methods related to achieving optimal inventory within an organisation operational process with the assistance of computer-based inventory information systems.

3. Supply chain management. It can be viewed as a practice to effectively manage the flow between customers' customers and suppliers' suppliers. Inter-company operations management of this nature is now more commonly termed supply chain management.

4. Material requirements planning (MRPI) and manufacturing resource planning (MRPII). They are two practices which have been implemented in planning and control functions of operational management. MPRI was developed in the 1960s and enables companies to calculate how much material of particular types are required, and what time they are required. During the 1980s and 1990s, the system and the concept of materials requirements planning has expanded and been integrated with other parts of the business. This enlarged version of MRP is now known as manufacturing resource planning (MRPII). MRPII enables companies to examine the engineering staffing and financial implications of future demand on the business, as well as examining the

materials requirement implications. MRPII was essentially aimed at the planning and control of production and inventory in manufacturing businesses. However, the concepts have been extended to other areas of the business. MRPII integrates separate databases held by different functional departments in order for the whole company to use and perform the functions properly or efficiently.

5. Just-in-time planning and control. It is a more recent approach or practice of operational planning and control functions than MRP. In practice, JIT method has the wider implications for improving operational performance. However, planning and control is its main function. JIT aims to meet demand instantaneously, with perfect quality and no waste. Theoretically, JIT can achieve the following benefits:

   - Continuous flow manufacture;
   - High value-added manufacture;
   - Stockless production;
   - Low-inventory production;
   - Fast-throughput manufacturing;
   - Lean manufacturing;
   - Enforced problem solving; and
   - Short cycle time manufacturing.

   In the theory, although MRP and JIT might seem to be very different approaches to planning and control, they can be combined to form a hybrid system, with different emphases, MRP for overall control and JIT for internal control. JIT covers many functions, like set-up time reduction (SUR), total productive maintenance (TPM), lead-time reduction, Kanban control, and etc.

6. Quality planning and control. It is a practice that is concerned with the systems and procedures, which govern the quality of the products and services supplied by the operation. Some operations managers believe that, in the long

run, quality is the most important single factor affecting an organisation's performance relative to its competitors. There are five classified quality planning and control approaches in operational management theory with different emphasis of each one. Each approach can be viewed as an individual quality planning and control practice. The five quality approaches are:

- The transcendent approach. This approach views quality as synonymous with innate excellence.
- The manufacturing-based approach. This approach is concerned with making products or providing services that are free of errors and that conform precisely to their design specification.
- The user-based approach. It is about making sure that the product is fit for this purpose.
- The product-based approach. It views quality as a precise and measurable set of characteristics that are required to satisfy the customer.
- The value-based approach. It takes the manufacturing definition a stage further and defines quality in terms of cost and price. This approach contends that quality should be perceived in relation to price.

In quality planning and control function of operations, there are other specific techniques to ensure quality of products during manufacturing process, such as, quality circles (QC), quality assurance (QA) and statistical process control (SPC).

Total quality management (TQM) is arguably the most significant of the new ideas which have swept across the operational management scene over the last decade. TQM is concerned more than quality alone. It is concerned with the improvement of all aspects of operations performance and particularly how improvement should be managed (Slack et al, 1995). TQM can be viewed as a logical extension of the way in which quality-related practice has progressed. Originally quality was achieved by inspection - screening out defects before they were noticed by customers. The QC concept developed a more systematic

approach to not only detecting, but also treating quality problems. QA widened the responsibility for quality to include functions other than direct operations. It also made increasing use of more sophisticated statistical quality techniques. TQM included much of what went before but developed its own distinctive themes. TQM represents a clear shift from traditional approaches to quality by specifically concerning the followings (Slack et al, 1995):

- Meeting the needs and expectations of customers;
- Covering all parts of the organisation;
- Including every person in organisation;
- Examining all costs which are related to quality;
- Getting things 'right first time', i.e. designing in quality rather than inspecting it in;
- Developing the systems and procedures which support quality and improvement; and
- Developing a continuous process of improvement.

Therefore, TQM is not just a function for planning and control. It is also a philosophy and can be viewed a way for operational improvement, which is reviewed afterwards.

Based on the review of planning and control function of operational management theory, the above six planning and control practices have been drawn but are not exhaustive. However, they are main ones presented and discussed in operational management literature. Theoretically, they are there to assist organisation operations performing properly and effectively in order to achieve performance objectives of an organisation.

Improvement

Even when an operation is designed and its activities are planned and controlled, it still need to be improved continuously, no matter how well it is managed. The practices within these functions of operation aim to improve the organisation's

operational and organisational performance.

There are two major approaches of improvement listed in operational management theory, breakthrough improvement and continuous improvement. Continuous improvement adopts an approach to improve performance which assumes more and smaller incremental improvement steps. Breakthrough improvement places a high value on creative solutions.

The business process re-engineering (BPR) approach is a typical one of the radical breakthrough way of tackling improvement. BPR has been defined as "the fundamental re-thinking and radical redesign of business process to achieve improvements in critical, contemporary measures of performance, such as cost, quality, service and speed" (Slack et al, 1995, page 749).

All the operational practices reviewed above attempt to improve some aspects of the performance of an operation and an organisation. Some techniques are particularly useful for improving operations generally, such as SPC and TQM reviewed before. Other techniques or analysis approaches, such as input-output analysis, flow charts, scatter diagrams and cause-effect diagrams, etc., are available in operational management theory to help to achieve improvement of an organisation.

TQM has been classified as a specific practice for operational improvement by Slack et al (1995). They stated that TQM ensures quality of every aspect of operation functions during the whole process. Therefore, theoretically, it is an effective practice for an organisation to achieve improved performance.

This sub-section (2.2.3) is summarised by the following table listing all the practices reviewed based on the theoretical literature of operational management.

Operational functions	Related Practices
Design	Investment in design
	R&D
	Cost-reduction in design
	Use of technology in design
	Quality management in design
	Interactive design
	Job-design-Human resource management
Planning and control	Capacity management
	Inventory management
	(including computer-based inventory information system)
	Supply-chain management
	MRPI and MRPII
	JIT (SUR, TPM, lead-time reduction, and Kanban)
	Quality planning and control (QC, QA, SPC and TQM)
Improvement	BPR
	Input-output analysis
	Flow charts
	Scatter diagrams
	Cause-effect diagrams

Table 2.1   Manufacturing Practices Summarised in the Context of Operational Management Theory

Table 2.1 includes three operational functions, which (manufacturing) operational practices are based on. Manufacturing practices can be generated or set in a wider context than the operational management. For example, unionisation and institutional ownership can be manufacturing companies' practices but they are set in industrial relations. This is explained further at the end of section 2.4 after the review of the manufacturing practices generated from the empirical studies. However, the essential and main stream of manufacturing practices is coming from operational practices, which are directly related to manufacturing in an organisation.

All the practices reviewed in this section with the rich context covering four classified sections of operational management literature are beneficial for improvement of performance theoretically. However, in real life, the results of implementation of these practices can be different from theoretical expectation because of the different ways that a practice is implemented or the different

situations in which it is set.

Due to different conditions in different organisations of different nations, the results of implementing an operational practice can be very different, even though it is beneficial theoretically. In the long term, one can trace the movement and development of operational management practices as they respond to conditions in one organisation and then are adopted by other ones to discover the general applicability of the practices. Therefore, investigation and analysis of empirical work on the results of the practices and their effects on organisation performance are meaningful.

The scope of this research is set on manufacturing operational management. Existent manufacturing practice factors and their effects on manufacturing firm performance are focuses. In the next section, manufacturing performance variables, measurement systems and approaches, which may be used to generate performance measures or systems, both from theoretical or empirical grounded, are reviewed.

2.3   Performance Variables

Relevant definitions of performance in a dictionary are 'act of performing, or deed or achievement'. As mentioned before, manufacturing performance in this research refers to achievements of a manufacturing company or an industry. Manufacturing performance measures are those which are employed in manufacturing companies or industries to measure their performance and provide actual meanings of definitions of performance.

Performance measurement is a large research topic, studied theoretically and empirically and provides groundwork for manufacturing relationship studies. In the operational management theory, performance measures have been developed and summarised in five objectives, reviewed in section 2.3.1. Furthermore, the relatively newly developed framework - the Balanced Scorecard (Kaplan & Norton, 1992, 1993 and 1996) in performance measurement theory is reviewed in section 2.3.1 as well.

The empirical work reviewed, the most common classification of performance variables simply splits them into financial and non-financial variables. Most studies have employed financial variables for performance measures, even though there are increasing emphases on the importance of non-financial measures. These studies (Fisher, 1992 and Maskell, 1991) emphasised that non-financial measures have an important role in today's competitive environment for companies achieving world class manufacturer status. However, a company that has improvement in its non-financial performance has to eventually reflect this improvement on financial performance measures.

One of the 45 published studies classified manufacturing performance variables according to throughput and output (Garsombke & Garsombke, 1989). Besides, a performance measurement framework measuring efficiencies in different management levels for manufacturing industry was developed by Hamblin (1990). Benchmarking is mentioned as a method to assist companies to generate their performance measures reviewed at the end of this section.

2.3.1   Performance Measurement in the Operational Management Theory

From operational management point of view, performance measurement is the process of quantifying action, where measurement means the process of quantification and the performance of the operation is assumed to derive from actions (practices) by its management. There are many developed performance measures. The common or traditional used way is employing individual performance measures. Besides, there are developed performance measurement systems, frameworks (such as the efficiency framework, the balanced scorecard) and outstanding approaches (such as Benchmarking). Using a performance approach, a set of performance measures can be developed for the organisation to measure its performance systematically and effectively. The performance measurement systems and approaches are not purely theoretical based. They have been widely implemented or used in management practices in companies or have been investigated in empirical research.

In this section, the fundamental performance measures developed in the operational theory are reviewed. In reality, performance measurement systems need to be developed consistently and continuous improvement is necessary for the organisation keeping successful in this changing world.

In the theory, five performance measures have been clarified and widely used. The five performance objectives are quality, speed, dependability, flexibility and cost, summarised by Slack et al (1995). Each of them contains subsidiary measures. For example, an operation's cost is derived from many factors which could include the purchasing efficiency of the operation, the efficiency with which it converts materials, the productivity of its staff, the ratio of direct to indirect staff and so on.

A 'bundle' of partial measures of the five performance measures have been developed to be used to make a judgement as to whether the operation or organisation's performance is good, bad, or indifferent. There are many ways to do so. However, comparing the current achieved level of performance with some kind of standard is commonly used.

The following standard measures regarding to the five performance objectives have been developed in the operational management theory.

Performance objective	Some typical measures
Quality	Number of defects per unit
	Level of customer complaints
	Scrap level
	Warranty claims
	Mean time between failures
	Customer satisfaction score
Speed	Customer query time
	Order lead time
	Frequency of delivery
	Actual *versus* theoretical throughput time
	Cycle time
Dependability	Percentage of orders delivered late
	Average lateness of orders
	Proportion of products in stock
	Mean deviation from promised arrival
	Schedule adherence
Flexibility	Time needed to develop new product/service
	Range of products/services
	Machine change-over time
	Average batch size
	Time to increase activity rate
	Average capacity/maximum capacity
	Time to change schedules
Cost	Minimum delivery time/average delivery time
	Variance against budget
	Utilisation of resources
	Labour productivity
	Added value
	Efficiency
	Cost per operation hour

Table 2.2   Some Typical Partial Measures of Performance
(Slack et al, 1995, page 731)

The current achieved performance can be compared with historical standards, target performance standards, competitor performance standards and absolute performance standards. Whatever comparison is taken, the purpose is to improve organisation performance.

Besides, a performance measurement framework called the Balanced Scorecard (Kaplan & Norton, 1992, 1993 and 1996) have been developed relatively recently

in the operational management theory to deal with multiple-dimensional performance measures.

In real life, managers realised that no single measure can provide a clear performance target or focus attention on the critical areas of the business. They want a balanced presentation of both financial and operational measures. Kaplan and Norton (1992) devised a "balanced scorecard" – a set of measures that gives top managers a fast but comprehensive view of the business. Their research was based on a year-long research project with 12 companies at the leading edge of performance measurement. The balanced scorecard includes conventional financial measures that tell the results of actions already taken, and it complements the financial measures with operational measures on customer satisfaction, internal processes, and the organisation's innovation and improvement activities-operational measures that are the drivers of future financial performance. The complexity of managing an organisation today requires that managers be able to view performance in several areas simultaneously.

The developed balanced scorecard allows managers to look at the business from four important perspectives (Kaplan and Norton, 1992):

- Customer perspectives-How do customers see us?
- Internal perspectives-What must we excel at?
- Innovation and learning perspective-Can we continue to improve and create value?
- Financial perspectives-How do we look to shareholders?

While giving senior managers information from four different perspectives, the balanced scorecard minimised information overload by limiting the number of measures used. The balanced scorecard forces managers to focus on the handful of measures that are most critical. There are successful cases of using the balanced scorecard (Kaplan and Norton, 1992).

With the experience of three companies, Rockwater, Apple Computer, and Advanced Micro Devices, Kaplan and Norton (1993) stated that the balanced scorecard provided executives with a comprehensive framework that translates a company's strategic objectives into a coherent set of performance measures. The three cases supported that the balanced scorecard complemented traditional financial indicators with measures of performance for customers, internal processes, and innovation and improvement activities. The best balanced scorecards are more than *ad hoc* collections of financial and non-financial measures. They link together in cause-and effect relationships from these four perspectives, therefore are effective (Kaplan & Norton, 1996).

2.3.2   Financial Performance Variables

The financial variables, which have been used in the empirical studies in manufacturing performance and practice relationships literature with the contribution of manufacturing performance measurement studies, fall into four different groups. These are 'return', 'growth', 'ratio' and general financial index.

Return:

The group of 'return' consists of absolute values and relative values of financial performance measures. Absolute values consist of profit, sales, market share and profit margin. The first two can also be decomposed further.

The following profit values have been employed: (1) trading or operating profit, (2) profit before interest and tax (PBIT or EBIT), (3) profit before tax (PBT or EBT), (4) Net income (net profit after tax), and (5) net income before extraordinary items (Oldcorn and Parker, 1996). Profit before tax is the most frequently used measure in the relationship studies. Sales cover domestic sales, export sales and total sales.

Relative values of 'return' include (1) return on investment (RoI), (2) return on asset (RoA), (3) return on sales (RoS), (4) return on capital (RoC), (5) return on equity (RoE), (6) return on common equity (RoCE), (7) return on net worth (RoNW), (8) total return on shareholders (TRS), and (9) total stock return (TSR).

They are calculated by profit (one of the profit values mentioned before) divided by a certain financial value, for instance, investment or capital. RoC can be the same as RoA if asset is used as a measure for capital. Except for asset which can be used as capital, the following items can also be used as capital: total assets less current liabilities, equity capital (shareholders' funds), equity plus long-term debt, and operating assets only (Oldcorn & Parker, 1996). The first four of relative values of returns are the most frequently used in this group in the relationship studies.

Besides these relative values of 'return', productivity and earning per share can also be classified into relative values of 'return'. The measures used for productivity are either total productivity, which is added value, or labour productivity, which is the actual hours required producing a product.

Growth:

'Growth' is a percentage change on the values of returns in two different time periods, mostly measured in the change in two consecutive years. Hence, the group of 'growth' includes (1) profit growth, (2) productivity growth, (3) sales growth, (4) market share growth, (5) profit margin growth, (6) RoI growth, (7) RoA growth, (8) RoS growth, (9) RoC growth, (10) RoE growth, (11) RoCE growth, (12) RoNW growth, (13) TRS growth, (14) TSR growth. Besides these, firm growth measured by the employment change per year is also counted in this growth group (Evans, 1987). The most often used growths in the relationship studies are consistent with the ones in 'return' group.

Ratio:

Three ratios have been used in the literature as financial performance variables, in addition to the relative return measures in the first group, if they are viewed as ratios. They are (1) price-earning (P-E) ratio which reflects a relative value of the firm's stock in the market, (2) firm's capital structure which is measured by debt-capital ratio, and (3) export ratio which is calculated by export sales divided by total sales (Chaganti & Damanpour, 1991 and Ito & Pucik, 1993). There may be

other ratios that could be used as financial performance variables. However, these three ones are the ratios which have been discovered in manufacturing practice and performance relationships literature.

General financial index:

This is a combined score for a set of financial measures used. The measures employed for calculating index can be equally weighted or be given different weights. For example, Covin and Slevin (1989) combined degree of satisfaction and the degree of importance of following financial performance criteria as a general financial index. Financial performance criteria they used were sales level, sales growth rate, cash flow, RoSE, gross profit margin, net profit from operation, profit to sales ratio, RoI, and ability to fund business growth from profits. The degree of importance was used as a weight to combine the degree of satisfaction to obtain a general financial index to measure the company financial performance. Both of the degrees were measured in a five-point Likert type scale, ranging from 'little importance' to 'extremely importance', or from 'highly dissatisfied' to 'highly satisfied' for importance and satisfaction, respectively. Of course, the internal reliability or consistency of these financial measures classified in a group should be evaluated before combining these measures. If, for example, one of the measures in the group is totally irrelevant or in the opposite direction with the others, the consistency of the measures can not be satisfied and therefore, the index calculated using these measures can not be reliable. There are tests or methods available to check the reliability or consistency of the measures in a group. The common used one is the reliability test employing Cronbach's Alpha.

2.3.3   Non-Financial Performance Variables

Non-financial performance variables have been used much less frequently in the published studies on the relationships between performance and practice in manufacturing industries than financial performance variables. Non-financial measures have been paid increasing attention in supporting manufacturing companies to make decisions. The following non-financial measures have been studied in the literature.

Quality is a most important non-financial performance variable and has been used much more frequently than other non-financial performance measures (Arthur, 1994; Macduffie, 1995; Meyer & Ferdows, 1990; Roth & Miller 1992 and Tunalv, 1992). Quality can be measured by defects rates or scrap rates. For example, defect rates, represented by the number of defects per 100 vehicles, were used to measure quality in an auto manufacturer (Macduffie, 1995); whilst scrap rates, represented by the number of tons of raw steel that has to be melted to produce one ton of finished product, were used to measure quality in a steel mini-mill (Arthur, 1994).

Flexibility has been mentioned in many manufacturing practice and performance studies (Roth & Miller, 1992; Tunalv, 1992). It can be decomposed into product, service, volume, delivery, and mix flexibility. Product and service flexibility can be measured by the degree of innovative products and services. Volume or delivery flexibility can be measured by the ability to change the timing or quantity of products and services. Mix flexibility can be measured by the range of products and services. The wider the range of products and services is, the higher the mix flexibility is.

Customer satisfaction is an important non-financial measure. In today's competitive environment, 70 percent of all sales derive from repeat purchases, i.e. from satisfied customers (Griffin et al., 1995). Therefore, customer satisfaction could be a valuable measure for performance. Customer satisfaction can also be used as a strategy and hence viewed as a practice factor. Customer satisfaction as a practice factor is included in the next section. The return rate of products has been used as a measure for customer satisfaction. However, there are different opinions about this measure. Customer satisfaction can also be measured by the degree of satisfaction about the products and services.

Innovation includes technical innovation and administrative innovation. Evan (1966, p.51) defined innovation as "by technical innovation, the implementation of an idea for a new product, process, or service; by an administrative innovation,

the implementation of an idea for a new policy, pertaining to the recruitment of personnel, the allocation of resources, the structuring of tasks, of authority, of rewards." Wacker (1987) defined it as the ability to design, manufacture, and market new products. It is clear that Wacker's definition refers to technical innovation. Nicholson and Brooks-Rooney (1990) studied innovation as a process and its relationship with other performance indicators.

Non-financial performance index is a combined score of non-financial measures. For example, non-financial performance index can be a combined score of following non-financial measures: quality conformance, inventory turnover, development speed, on-time delivery, delivery speed, etc (Meyer & Ferdows, 1990).

Lead time, on-time delivery, delivery speed and dependency (reliable delivery) have been mentioned and been used as non-financial performance variables in the 45 studies (appendix 1).

2.3.4   Measuring Efficiencies-A Performance Measurement Hierarchical Framework

Labour efficiency and total productivity has been mentioned in the previous section as of the performance measures used in the 45 manufacturing practice and performance relationship studies. Besides, the hierarchical performance measurement framework proposed by Hamblin (1990) consists of a series of performance variables measuring the efficiencies of different levels of manufacturing companies or industries' performance. The basic hierarchy consisting of three levels' efficiency measures is given in figure 2.5.
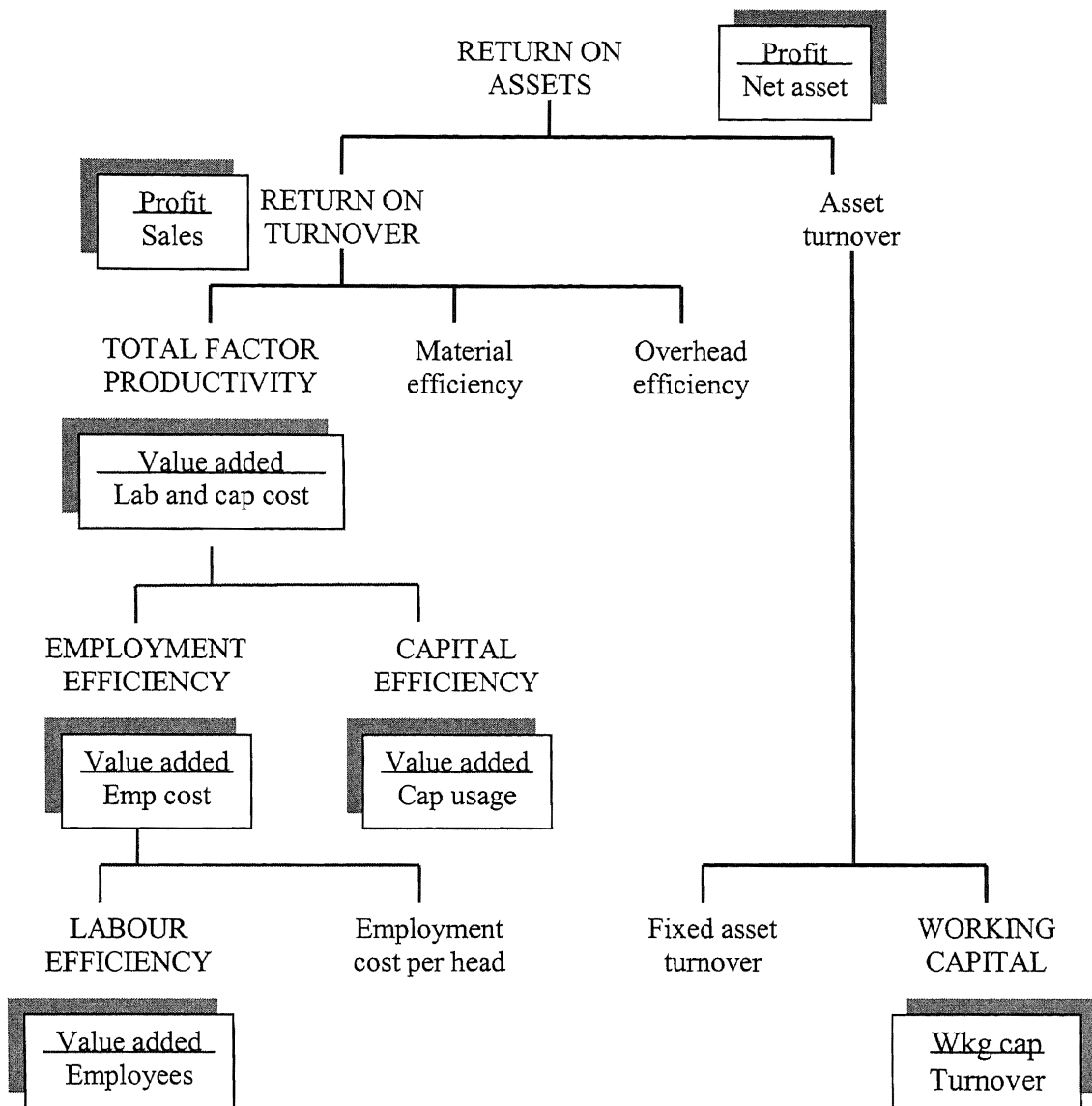
Figure 2.5   **Measuring Efficiencies Hierarchical Framework**
                    (Hamblin, 1990)

The efficiency measures in the framework include:

(1) Labour efficiency, which is value added divided by the number of employees,

(2) Employment efficiency, which is value added divided by employment cost and is dependent on labour efficiency,

(3) Capital efficiency, which is value added divided by capital cost, and

(4) Total Factor Productivity (TFP), which is value added divided by the sum of

employment cost and capital cost and is dependent on employment and capital efficiencies in a lower level.

The advantages of using productivity ratios and efficiency ratios based on added value have been discussed by Hamblin (1990) and Hamblin and Iyer (1996) in detail.

2.3.5   Throughput and Output Performance Variables

One of the 45 relationship studies (Garsombke and Garsombke, 1989) classified performance variables into throughput and output.

In detail, throughput performance variables are those which are used to measure production or operation process performance. Output performance variables are those which are used to measure the results of a company's performance and mostly related to financial or marketing factors.

There are 15 throughput performance variables according to Garsombke and Garsombke (1989). They are: production output, lead time, material flow, inventory safety stocks, WIP or finished goods, throughput time, production set-up time, rework costs, scrap costs, production changeover time, no. of production employees, production changeovers, unit production output, stage of new products and number of materials handling equipment.

There are 12 output performance variables which have been classified by Garsombke and Garsombke (1989). They are: profit margin, sales, RoI, number of employees, equipment utilisation, market share, payroll costs, sales area, accounts receivable, employee wages, customer base, and new product lines.

In summary, performance variables have been reviewed in this section. They mainly came from the 45 manufacturing performance and practice relationship studies. Performance measure studies also contribute to these lists. Research on performance measurement issues is a rapidly developing field. It has to be mentioned that it is impossible to cover all performance measures in the literature.

The manufacturing performance measures reviewed in this section cover the main stream of manufacturing performance literature and provide broad information for further manufacturing performance and practice relationship studies in this research.

2.3.6   Benchmarking

In operational management, benchmarking is defined as an approach which companies use to compare their operations with those of other companies (Slack et al, 1995). Benchmarking was used by the Xerox Corporation and was described as a process "used by the manufacturing function to revitalise itself by comparing the features, assemblies and components of its products with those of competitors" in 1979. But now it has been widely used in many different functional areas and different types of organisations.

Benchmarking can help the company to achieve two objectives. At a strategic level it helps set standards of performance whilst at an operational level it helps the company understand the best practices and operations methods which can help it achieve its performance objectives.

There are many different types of benchmarking (which are not necessarily mutually exclusive), some of which are listed below (Slack, et al, 1995).

- *Internal benchmarking* is a comparison between operations or parts of operations which are within the same total organisation.
- *External benchmarking* is a comparison between an operation and other operations which are part of a different organisation.
- *Non-competitive benchmarking* is benchmarking against external organisations which do not compete directly in the same markets.
- *Competitive benchmarking* is a comparison directly between competitors in the same, or similar, markets.
- *Performance benchmarking* is a comparison between the levels of achieved performance in different operations.
- *Practice benchmarking* is a comparison between an organisation's operations

practices, or way of doing things, and those adopted by another operation.

In this section, benchmarking refers to performance benchmarking, which is used to select the best suitable performance measures regarding to the company's situation by comparing with other companies. Benchmarking is partly concerned with being able to judge how well an operation is doing. Benchmarking is essentially about stimulating creativity and providing an incentive which enables operations better to understand how they should be serving their customers. Many organisations find that benchmarking is the process itself of looking at different parts of their own company or looking at external companies which allows them to understand the connection between the external market needs which an operation is trying to satisfy and the internal operations practices it is using to try and satisfy them. There are five phases developed in practice to implement benchmarking approach. These five phases are planning, analysis, integration, action and maturity. The detail of these five phases are given by Slack et al (1995, page 733).

Benchmarking is a valuable management tool which helps to identify that set of practice which a good company uses. It does not, however, seek to explain the contribution of each individual practice to the performance achieved. For this purpose practice-performance relationship studies using longitudinal and/or cross-sectional data set are needed.

In this section, performance variables and measurement systems and approaches have been reviewed. In the following section, practice factors generated from empirical studies in the past are reviewed in detail.

2.4   Practice Factors Generated from Empirical Studies

Relevant definitions of practice in a dictionary are 'a doing or effecting' and 'exercise of any profession'. In this study, practice refers to manufacturing management practice, or manufacturing management doings or exercises. In another way, practice in this research is a kind of management action, which can be employed in manufacturing companies in order to improve their performance.

The manufacturing management actions explored in the literature are listed in this section and the definitions for these actions are also provided, which give 'practice' actual meanings.

A wide range of the practice factors has been explored in the manufacturing performance and practice relationships literature. Also, best practice studies contribute to the selection of practice factors. These practice factors are catalogued into 24 groups, although there are necessary overlaps between the groups and it would be unusual to have actions which are only effective in one group.

1. Lean Production. Including Just in Time (JIT), Work in Process (WIP), set-up time reduction, manufacturing lead time reduction, and buffer reduction and production control. Some of these practice factors overlap each other but with different content focuses. For example, JIT programme includes the content of set-up time reduction. The reason why set-up time reduction is listed separately from JIT is that some companies only implemented set-up time reduction but not the whole process of JIT and some studies only investigated set-up time reduction but not entire process of JIT based on the companies' real practice situations.

2. Human Resource Management (HRM) related programmes. Including developing HRM policies (such as commitment policies), direct labour motivation, multiple-skill training, giving workers a broader range of tasks, and giving workers more planning responsibilities.

3. Diversification. Including product diversity, geographic diversity, service diversity, and market diversity.

4. Quality Management. Including Total Quality Management (TQM), Continuous Quality Improvement, zero defects, statistical quality control (process) and quality circles.

5. New Product Development. New product development activities include

product flexibility (customisation), new product introduction, design quality (design innovation), product development cycle time, product technological innovation, product improvement refinement, new product development, and original product development. The paper by Calantone, Vickery and Droge (1995, page 216) gave the detailed definitions of these new product development activities.

6. Research and Development (R&D). R&D related factors include amount of R&D expenditure, firm R&D intensity, industry R&D intensity, process R&D and product R&D.

7. Use of technologies. Including use of automation, robotization, computerization and information systems in manufacturing management control, design and production process.

8. Flexible Manufacturing Systems. Including any forms of manufacturing systems which can be defined as a computer-controlled configuration (flexible manufacturing cell) of semi-independent work stations connected by automated material handling and machine loading (flexible transfer line).

9. Capital Investment. Including any forms of long term financial investments in capital assets, such as investment in land and buildings, investment in technology and investment in equipment.

10. Size of firm. Including employment size measured by the number of employees, property size measured by assets and operational size measured by the number of plants which a firm operates.

11. Unionisation. Including improving labour/management relationships and union co-operation.

12. Focus. Including plant focus, corporate focus and production process focus

which means either small batches, large batches (or an assembly line) or a continuous process.

13. Strategic planning. Formal planning with consideration of the strategies of a manufacturing company.

14. Cost reduction. Programmes related to reducing cost.

15. Age of firm. The number of years' existence of a manufacturing company.

16. Export. Including increase in export sale amount in volume/value or the ratio of exports to total sales.

17. Institutional ownership. Including outside institutional shareholdings, inside and family institutional owners' shareholdings and corporate executives' shareholdings.

18. Environment. Including the degree of hostility in eg. acquisitions.

19. Restructure. Any types of reforms carried out in manufacturing companies.

The following five variables are also surrogated for performance variables even though some studies in this literature used them as practice factors. They share double status.

20. Market share. The activities related to increase in the percentage of products in the market.

21. Customer satisfaction. As mentioned in last section, customer satisfaction can be used as a non-financial measure for performance. There is a study employing customer satisfaction as a good practice, which is linked to improve firm performance measured by financial variables, such as RoI, economic returns

and market value. In this case, customer satisfaction is viewed as part of a strategy (Griffin et. al., 1995).

22. Firm value. It is often measured by earning per share.

23. Long term debt, and

24. Dependability. Including delivery reliability

The performance variables and the practice factors employed in manufacturing areas have been introduced in the above two sections. It is impossible to cover everything. However, it is believed that the variables listed above cover a wide range to be sufficient to form the basis for the relationship studies in this research.

Most of the practices summarised from empirical works included are coming from the theory of operational management. There are other factors drawn from the published studies, such as diversification, size and age of the firm, unionisation, export and firm value, which have been considered as manufacturing practices in this study. Some of them can be included in the domain of operational management, such as diversification. Some of them should belong to other domains in management science, such as unionisation, which should be classified in industrial relations. This research has no intention to review all management science theory because it is a large subject and most of the context has no direct relation with this research. The key practices pertinent to manufacturing practices have been summarised.

2.5   Manufacturing Practices and Performance Relationships

Empirical studies on the relationships between practice and performance can be categorised into 24 groups according to the 24 practices listed in last section. The studies on this literature focus mainly on whether and how these practices effect manufacturing performance measured by financial and/or non-financial terms. The influence of manufacturing performance, vice versa, on implementing practice is not the main concern in these relationship studies.

In these 24 categories, the seven most intensively studied relationships are the following factors, lean production, HRM related programmes, diversification, quality management, new product development, use of technology and FMS, and manufacturing performance. There is remarkable consistency in the positive results on new product development (Calantone et al., 1995; Sa, 1988; Voss et al., 1995; O'Mahony, 1994 and McGrath & Romeri, 1994), quality management (Banker et al., 1993; Kasul & Motwani, 1995; Tunalv, 1992; Wacker, 1987; Roth & Miller, 1992; Shadur, 1995 and Young et al., 1988) and FMS (Tunalv, 1992; Covin & Slevin, 1989 and Macduffie, 1995) on performance improvements, whatever the methods and measures have been used and wherever the data was collected for the investigations. However, the studies into effect sizes of new product development on performance showed differences. Whether the difference is significant or not needs to be explored. Most studies on quality management and FMS are qualitatively based and there is insufficient information on their effect sizes on manufacturing performance. Nevertheless, new product development, quality management and FMS were quite promising for improvements of manufacturing performance and supported by the research in the past.

The studies on lean production (Meyer & Ferdows, 1990; Wathen, 1995; Wacker, 1987; Banker, et al., 1993; Schmenner & Rho, 1989; Voss et al., 1995; Mayer, 1989; Sellani, 1994 and Oliver et al., 1994), HRM related programmes (Macduffie, 1995; Arthur, 1994; Roth & Miller, 1992; Schmenner & Rho, 1989; Banker et al., 1993; Corbertt & Harrison, 1992 and Ng & Maki, 1993), diversification (Chang & Thomas, 1989; Fowler & Schmidt, 1989; Evans, 1987; Arthur, 1994; Carpano et al, 1994; Habib & Victor, 1991; Dubios et al., 1992 and Sa, 1988) and Use of Technology (Roth & Miller, 1992; Carr, 1988; Garsombke & Garsombke, 1989 and Sa, 1988) provide different findings, despite qualitative or quantitative methods being used on the assessments on their relationships with manufacturing performance. The literature provided quite controversial findings on diversification strategy and use of technology in the manufacturing

relationships literature. However, diversification strategy has been viewed as a way out in nowadays competitive environment. Technology advances may still be very beneficial for a company in the long term. The degrees of controversy on HRM related programmes and lean production are much less and may more likely depend on the elements which have been included. The results on these two practices have a trend towards a positive effect on manufacturing performance.

Besides these seven most frequently studied relationships, capital investment showed quite a consistent positive effect on performance. However size and age of the firm have less consistent effects on benefiting performance in the past.

2.6   The Need of Clarification of the Findings on the Manufacturing Practice and Performance Relationship Studies

There are several problems related to the general application (validity) of the outcomes of an individual study, internal validity, external validity and statistical conclusion validity. The results or conclusions generated from a single study are constrained by research situational specification, i.e. conditioned in certain time period, a certain studied country or industry and other factors related to the study environment. When a practical situation is different from the one investigated, the findings related to this relationship may not be valid in the new practical situation and hence can not be applied. In addition, the research on the manufacturing practice and performance relationship also provided different findings, which make the application of the findings unfeasible.

The differences of the findings on the relationships could be analysed by comparing the situations in which the studies were carried out. This may uncover the elements causing differences, but whether the differences are significant can not be explored. However, in this study, we are concerned with the acceptance of the differences. If the difference is not significant, the results of the findings may be combined and the combined results can be applied in general. A method is required to combine the different findings and analyse the difference in the relationships. It helps to decide whether the findings related to a certain relationship can be applied in general or otherwise to uncover gaps in the

manufacturing relationship studies. Meta-analysis (Glass, 1976) provides a methodology which can be used to combine differences of findings concerning with relationships. The errors caused by samples and measurement and other factors are considered and reduced and therefore, the acceptance of the findings of a certain relationship in general can be decided at a certain confident level.

2.7   Summary

In this chapter, external/economic factors and internal factors to firms from a theoretical point of view have been reviewed first to provide a big picture and fundamental background for further investigating the relationships between manufacturing practice and performance. In order to do so, empirical works on performance variables and practice factors and their relationships have been searched and reviewed and factors have been summarised. These factors are mainly drawn from manufacturing practice and performance relationship studies in the literature. However, performance measurement studies and best practice studies also contribute to the review results. Most of these factors are come from operational management theory and some are from other subjects in management science. Nevertheless, all these factors are viewed as manufacturing practices in this study.

Five performance objectives and sub-measures developed in the operational management theory have been reviewed first. Drawn from the empirical studies, performance variables have been classified into financial and non-financial measures. Also, other performance measurement systems or approaches, the efficiency measurement system, the throughput and output system, Benchmarking, and Balanced Score Cards, are also reviewed. Financial measures in performance have been paid much more attention comparing with non-financial measures. The performance measures used in companies or studied by researchers reflect the perspectives from which they perceive their success. Also, twenty-four catalogues of practice factors have been summarised based on the empirical studies in the past.

The relationships between practice and performance in the manufacturing domain

have been reviewed. The findings on certain relationships are consistent in some aspects. However, there are still quite a few relationships with different findings, especially on the sizes of the relationships. Whether these inconsistencies are due to difference in population or rather simply due to other factors such as sample error needs to be discovered.

Meta-analysis provides a method to integrate these individual findings to determine whether the difference in the findings is acceptable or not, thereby to establishing a base for future research in general and some reference for practitioners. The next chapter introduces meta-analysis methodology and applies it to the manufacturing practice and performance relationships studied in the past.

Chapter 3   Meta-Analysis of the Relationships between Practice and Performance in Manufacturing Industry

3.1   Introduction

Meta-analysis (Glass et al., 1981, Hunter et al., 1982, Wolf, 1986) is a methodology to integrate and analyse different empirical results on relationships. As mentioned in the previous chapter, the literature search on manufacturing performance and practice relationship discovered 45 studies and provided different results on these relationships. This search covered the period from 1979 to 1995 inclusive. However, the 45 articles actually ranged from 1986 to 1995 due to no relevant studies being uncovered from 1979 to 1985 in manufacturing relationship studies. Therefore, meta-analysis is employed to present an overview of published studies of the practice-performance relationships in manufacturing industry during this time period. 16 of the 45 studies provide relevant quantitative information of the relationships, such as correlation coefficients, which make the assessment of the sizes of the certain relationships possible. The different findings of the relationships between practice and performance can be clarified not only qualitatively but also, for some of the relationships, can be explored quantitatively as well.

The published studies on manufacturing practice and performance relationships have been searched in two computerised data bases, ABI/Inform and Institute of Management Database (IMID), and relevant references provided by published studies during the review. The key words were "manufacturing" and "performance". More than 200 articles have been found related to manufacturing performance. 45 articles have studied the relationships between practice and performance, and therefore, have been included into this meta-analysis. The reason why the key words for the searching omitted to include "practice" is because "practice" can be expressed by different terms and only one article came out when practice was used for a key word. The included articles provided at least (1) a dependent variable measuring some aspect(s) of manufacturing performance

(financial or non-financial measures), and (2) an independent variable representing a practice factor. The 45 articles cover 25 different academic journals whose frequencies are provided at table 3.1. The full references of these 45 articles are provided at appendix 1. Appendix 1 also provides a table of the scope and findings of the 16 studies of these 45 which employed quantitative methods.

Sources of the meta-analysis studies	No.	Sources of the meta-analysis studies	No.
Long Range Planning	7	Inter. Journal of Human Resource Mgt	1
Strategic Mgt. Journal	6	Inter. Journal of Quality & Reliability. Mgt.	1
Inter. Journal of Oprtns & Prdctn Mgt.	5	Inter. Studies of Mgt. and Organization	1
Production and Inventory Mgt. Journal	4	Journal of Business Strategies	1
Journal of Inter. Business Studies	2	Journal of Economic Studies	1
British Journal of Mgt.	2	Journal of Operations Mgt	1
Academy of Mgt. Journal	1	Journal of Small Business Mgt.	1
Accounting Organization and Society	1	Mgt. International Review	1
Business Finance & Accounting	1	National Institute Economic Review	1
Business Horizons	1	Production Innovation Mgt. Journal	1
British Journal of Industrial Relations	1	Sloan Mgt. Review	1
Industrial and Labour Rlatns Review	1	The Journal of Industrial Economics	1
Interface	1	Total	45

No: Number of the studies included in the selected journal

Table 3. 1   The Summary of the Studies included in the Meta-Analysis

Therefore, this chapter covers the following aspects:

1. Introduction of meta-analysis methodology, especially two methods in this methodology

2. Classification of performance variables and practice factors used in the meta-analysis

3. Results of the meta-analysis of the two methods applied

4. Limitations of meta-analysis

3.2   Meta-Analysis Methodology

Meta-analysis, initially developed by Glass (1976), is a research approach in which the results from many empirical studies examining relationships between similar variables are systematically combined and integrated. The aim of meta-analysis is to reveal patterns of relatively invariant underlying relations and

causalities between variables, the establishment of which will constitute general principles and cumulative knowledge (Hunter, et al., 1982).

Based on the availability of the literature in the area of relationships between performance and practice in manufacturing industry, two forms of meta-analysis are conducted in this chapter. First, a counting approach (Capon et al., 1990), using counts of significant relationships, helps establish the general shape of the literature. What has been studied a great deal and what has not in manufacturing performance and practice relationships can be clear. This is a simple, robust method involving three steps:

1. Cataloguing the relationships in terms of their independent and dependent variables;
2. Identifying the sign of each empirical relationship (positive or negative) and counting the number of positive and negative signs for each relationship; and
3. Testing the sign of each catalogued relationship using binomial sign test (Spiegel, 1972, page 122).

Through these three steps, whether a certain relationship reported is significantly more positive than negative or significantly more negative than positive can be determined according to the result of a binomial sign test. Sometimes, a test provides a result that insufficient information has been reported in the literature to decide whether the relationship reported is significantly more positive or significantly more negative. When there is no sufficient information which has been reported or studies in the literature for a certain relationship, it means there is a gap in the literature and further research for this relationship is needed.

This method is extremely flexible since it requires only qualitative assessment of relationships. But its main disadvantage is that the outcome is also qualitative-the existence of a relationship is established but its size cannot be estimated. The

second method of meta-analysis can remedy this disadvantage, provided correlation coefficients for the relationships are available in published research. The second approach measures the effect size. It enables us to quantify systematic similarities and differences in relationships. This is conducted through combining the correlation coefficients that have been reported in the empirical studies and reducing artefact errors to estimate population means-strength of relationships. According to Hunter et al. (1982), much of the apparent contradiction of the findings in empirical research is the product of statistical artefacts rather than population differences. There are several artefacts that can explain much of the variance observed among studies, such as sampling error, measurement error, and computational and typographic errors. Among these artefact elements which may cause the observed variance, sampling error can account for 75 to 95 percent of the error across studies (Schmidt, et al., 1981; Terborg et al., 1982; Schmidt et al., 1980). In section 3.5, the correlation coefficients across a collection of these studies are aggregated and the variances caused by sample-error are calculated to explain some of the observed variance.

In this second form of meta-analysis, there are four basic steps required to derive mean correlations and variance estimates (Hunter, et al., 1982).

The first step is to estimate the population mean correlation for the collection of i studies (correlation coefficients r_i) under review by calculating an average correlation coefficient $\bar{r}$ weighted by sample size (N_i).

$$\bar{r} = \frac{\sum N_i r_i}{\sum N_i}$$

Since large sample studies are subject to less sample error, a weighted average correlation will provide a more accurate aggregated estimate of the population mean than a simple average.

The second step is to calculate the observed variance (σ_r^2) among individual correlation coefficients across studies using an average squared error $(r_i - \bar{r})^2$ weighted by sample size (N_i):

$$\sigma_r^2 = \frac{\sum N_i (r_i - \bar{r})^2}{\sum N_i}$$

Because sampling-error variance is a major influence which causes observed variance bigger than population variance, the third step is to calculate an estimate of sampling-error variance (σ_e^2) (the variance which is caused by sampling-error rather than population difference). Then observed variance can be corrected by sampling-error variance to estimate population variance.

$$\sigma_e^2 = \frac{(1 - \bar{r}^2)^2 k}{\sum N_i}$$

Where k is the number of individual correlations included in the calculation. Then i is from 1 to k. Then the last step is to obtain the unbiased estimate of the population variance (residual variance) by subtracting the sampling error variance from the observed variance:

$$\sigma_\rho^2 = \sigma_r^2 - \sigma_e^2$$

This four-step procedure provides estimates of population mean correlations and variance that are corrected for sampling error.

The smaller corrected population variance indicates higher percentage of total variance explained by sampling error variance and higher degree of acceptance of the combined results. The combined results on relationships with more than 75% of total variance explained by sample error variance is a criteria for acceptance of the combined results (Pearlman et al, 1980). The detail of its application for this research is given in section 3.5.

Corrections for other statistical artefacts could not be made in the present meta-analysis because the necessary information (e.g. reliabilities of the measurements used in the empirical studies) for these corrections were not reported by many studies included. Similar difficulties have been mentioned in several meta-analytic works (Gooding & Wagner III, 1985; Capon et al., 1990). Therefore, conclusions drawn from this research are based on somewhat conservative estimates of population mean correlations and variance.

3.3   The Classification of the Variables included in the Meta-Analysis

In section 2.2 and 2.3, the performance variables and practice factors which are investigated either in relationship studies or performance measurement studies or best practice studies have been included and classified. In this section, the variables used only in the relationship studies are relevant to the meta-analysis and are included in the classification. The classification in this chapter is therefore different from the one in chapter 2. Both the lists of performance variables and practice factors in this chapter cover fewer items than the ones in chapter 2.

3.3.1   Practice Factors

The 45 published studies investigated relationships between a wide range of practice factors and performance variables. These practice factors have been classified into 23 variables based on the specific or general type of practice improvement which is intended, and on the desire to identify adequate cases for analysis in each class; this leads to some broad practice categories alongside some specific categories. They are:

1. *Lean Production.* Including JIT, WIP, set-up time reduction , manufacturing lead time reduction, buffer reduction and improved production control;

2. *HRM related programmes.* Including HRM policy change (such as commitment policies), direct labour motivation, and multi-skill training;

3. *Diversification.* Including increases in the degree of product and geographic diversity;

4. *Quality management*. Including TQM, Continuous Quality Improvement, zero defects, statistical quality control and quality circles;

5. *New product development*. Including new product development activities and R&D related factors. New product development activities include product flexibility (customization), new product introduction, design quality (design innovation), product development cycle compression, product technological innovation, product improvement refinement, new product development, and original product development. R&D related factors include amount of R&D expenditure, firm R&D intensity, industry R&D intensity, process R&D and product R&D;

6. *Use of technologies*. Including use of automation, robotics, computerization and information systems;

7. *Flexible Manufacturing Systems*;

8. *Capital investment* - long term investment in capital assets;

9. *Size of firm*. Including employment size measured by the number of employees, property size measured by assets and operational size measured by the number of plants a firm operates;

10. *Unionisation*. Including improving labour/management relationships and union co-operation;

11. Strategic *Focus*. Including increasing plant focus, corporate focus and production process focus;

12. *Strategic planning*. (formal planning);

13. *Cost reduction*;

14. *Age of firm*;

15. *Proportion of Export sales*;

16. *Institutional ownership*. Including outside institutional shareholdings, inside and family institutional owners' shareholdings and corporate executives' shareholdings;

17. *Hostility/Environment*. Including the degree of hostility in e.g. acquisitions;

18. *Restructure*;

Variables 19 to 23 have been employed by the studies included in this meta-analysis as practice variables, even though they also surrogate for performance variables. They share double status.

19. *Market share*;

20. *Customer satisfaction*;

21. *Firm value* (earning per share);

22. *Long term debt*;

23. *Dependability*.

All of the above 23 practice variables have been taken into account for the first form of the meta-analysis. In the second form of the meta-analysis, 7 of the 23 variables are used, of which one has been split. They are:

1. new product development including R&D factors

2. new product development excluding R&D factors

3. firm size

4. strategic focus

5. human resource management related programmes

6. firm age

7. diversification

8. hostility of environments.

In addition to these 8 variables, "action programmes" have been used as a specific practice variable only for the second meta-analysis. The action programmes included quality conformance, unit production cost, inventory turnover, development speed, on-time delivery, delivery speed, overhead costs and batch size related programmes, encompassing variables 1, 4 and 13 of the first list.

Some practice variables are excluded in the above classifications because only one or two correlation coefficients related to these variables (such as ownership and

unionization), and therefore the second form of meta-analysis could not be applied.

3.3.2   Performance Variables

In the first form of meta-analysis, any performance improvement is considered as valuable to the firm, and since it is a basic combining technique, there is limited value in classifying the types of improvement. However, in the second form of the meta-analysis, it is desirable to classify the performance variables to improve understanding of the underlying relationships.

First, performance variables have been divided into financial variables and non-financial variables. Based on the 16 included published studies reporting information qualified for the second form of the meta-analysis, financial variables have been arranged into two groups which are 'return' and 'growth', one general financial index and one specific variable. As with the practice variables, studies are classified to the specific categories where possible based on the published data:

1. Return. Including return on investment (RoI), return on sales (RoS), return on assets (RoA), return on equity (RoE), return on capital employed (RoCE), productivity, profitability, market share and sales;
2. Growth. Including RoI growth, RoS growth, market share growth, firm growth (employment change per year);
3. General financial index, being a combined score for the financial measures used;
4. Labour productivity.

Non-financial performance variables have been used much less in the published correlation studies than financial variables:

5. Non-financial index, being a combined score for non-financial measures used.
6. Quality is measured by defects rate or scrap rate.

One study (Garsombke and Garsombke, 1989) of 16 correlation studies used an overall performance index and could not be included in the meta-analysis.

After classifying the variables and cataloguing their relationships, the sign of each empirical relationship needs to be identified and adjusted for compatibility before integrating them. In principle, the direction which is widely held to be an improvement is taken as the standard for the performance variable, therefore all positive practice-performance relationships are notional improvements. For example, the correlation between "Quality" and "HRM" where "the number of vehicles *without defects* in 100 new produced vehicles" was used to measure the "Quality" was positive; whilst the correlation between them where "the number of vehicles *with defects* in 100 new produced vehicles" was used to measure "Quality" was negative. Clearly, these two opposite correlation coefficients mean the same thing, i.e. "HRM" is related to improved quality performance. The signs of correlations have to be adjusted to be consistent before combining individual correlation coefficients in meta-analysis. If not, the results of a meta-analysis would obviously not be valid. In some classes, specifically 3, 9, 12, 14, 15, 16, 17, 18 there is no widely held view of improvement direction and an arbitrary but consistent positive direction is taken in each class.

3.4   Results of the Counting Approach and Interpretation

Based on the total sample, the 45 published studies on manufacturing performance and practice relationships, 16 classes of the relationships between manufacturing practice and performance which have been reported in at least 3 studies have been summarised and provided in table 3.2. The 16 classes of the relationships between manufacturing practice and performance are catalogued according to practice variables. The practice variables as independent variables which are associated with a single dependent variable (performance) are listed in the first column of table 3.2.

| Independent Variables | N | No of Relationships | | | Binomial | Signifi |
		Pos.	Neg.	Total	Results(p)	cant?
Lean Production	10	10	3	13	0.046	+
HRM related Programmes	9	9	1	10	0.011	+
Diversification	8	12	5	17	0.072	ns
Quality Management	7	8	0	8	0.004	++
New Product Development	6	15	0	15	0.000	++
Use of Technology	6	11	6	17	0.166	ns
FMS	6	9	0	9	0.002	++
Capital Investment	5	9	0	9	0.002	++
Firm Size	5	4	5	9	0.746	ns
Unionisation	4	2	3	5	0.813	ns
Focus	4	3	2	5	0.500	ns
Strategic Planning	4	3	1	4	0.313	*
Cost Reduction	4	3	1	4	0.313	*
Firm Age	3	5	3	8	0.363	ns
Export	3	4	0	4	0.063	*
Market Share	3	1	2	3	0.875	*

++, +:   significantly more positive than negative relationships reported, based on sign test at a level of 0.01 or 0.05

ns: not significantly difference between the number of positive and the number of the negative signs

*:   insufficient relationships reported to draw conclusions by binomial tests

N: number of the studies included

Table 3. 2   Counts of Sign of Practice Factors Studied with Manufacturing Performance Relationships

Table 3.2 shows the practice variables in rank order of study frequencies, with the number of studied (N), the number of positive, negative and total relationships cited, and the results of the binomial sign test for each relationship cited. It shows that the practice factors (independent variables) which have been explored in published studies are very diverse. 16 classes of the independent variables were repeated in at least three studies.

There are a further seven independent variables which were not included in table 3.2 because they were only explored in one or two studies. They are ownership, long-term debt, environment, firm value (earning per share), dependability, restructure, and customer satisfaction. Because the total number of published studies in this area is relatively small and covers a wide range of independent

variables, the number of studies related to each of the independent variables is small, even though some studies reported more than one independent variable. For five classes only positive relationships have been reported, however for the remaining eleven groups both signs of the relationships have been reported, which generates confusion for practitioners.

Based on the binomial sign tests ($\alpha = 0.05$), there are six classes where significantly more positive than negative relationships were reported. They are: (1) Lean production; (2) HRM related programmes; (3) Quality Management; (4) New Product Development; (5) Flexible Manufacturing Systems; and (6) Capital investment-long term investment. Classes 3 to 6 are significant even at 1 percent level. These six factors can be suggested as important practices related to manufacturing performance improvement.

Another six classes show no significant relationships with this relatively small sample of published studies. They are: (1) diversification; (2) use of technology; (3) firm size; (4) unionisation; (5) focus and (6) firm age. There may be two reasons for the outcome. One is that there is indeed no significant relationships (either positive or negative), especially when the relationships are relatively specific, i.e. independent variables of the relationships include only a couple of elements. For instance, the practice of "diversification" only covered two elements - product and geographic diversification. The result of the binomial test for this relationship which shows no significance can be accepted. The other reason is that the classification of practice is too general and the relationship could be further explored at a more specific level. For instance, "use of technology" included use of information systems, robotization, computerisation and automation. The relationships between "use of technology" and performance can be further explored, in which case the result could be different for each technology. In this study, however, the results still showed no significance because of the very small sample size (less than five) which each of the four independent elements of "use of technology" holds.

The other four relationships included very small sample sizes (not more than four). The results showing no significance were present because insufficient numbers of a certain relationship reported in the literature. Hence valid conclusions cannot be drawn. They are the relationships between strategic planning, cost reduction, export and market share with performance. It will be noted (see "export") that four correlations alone are insufficient to draw a significant conclusion based on the result of the binomial sign test, even though all four of them are in the same direction, in this case all of them are positive. At a significance level of 0.05, at least five repeated relationships are required to be reported at the same direction to show a significant result.

3.5   Results of the Measuring Effect Size Approach and Interpretation

Based on 16 of the 45 published studies concerning the relationships between manufacturing performance and practice which provided correlation coefficients, 10 groups of the associations of the practice factors (independent variables) with the different performance measurement variables (dependent variables) and their combined effect sizes are reported in table 3.3. Besides, total sample sizes, number of correlations included in the combination (k), observed variance, sample error variance, residual variance and percentage of observed variance explained by sample-error variance.

Independent variables	Dependent variables	k	Total sample	Weighted mean r	Observed variance	Sampl.-E variance	Residual variance	Percentage explained
NPD /R&D	Return	12	1584	0.535	0.061	0.0039	0.057	6.3
Size	Financial	3	360	0.534	0.186	0.0043	0.181	2.3
Focus	Return	3	318	0.514	0.268	0.0051	0.263	1.9
HRM	Quality	4	216	0.446	0.016	0.0119	0.004	74.0
HRM	Lab Prody.	4	216	0.437	0.063	0.0121	0.050	19.4
Action prog.	Non-Fin	11	440	0.425	0.045	0.0167	0.028	37.5
Age	Financial	3	114	0.352	0.046	0.0202	0.026	44.1
NPD	Growth	8	455	0.351	0.001	0.0018	0	100.0
Hostility	Return	8	791	0.263	0.029	0.0076	0.022	26.3
Diversificn	Return	5	271	0.094	0.018	0.0181	0.000	99.1

k: number of correlations included in analysis

Table 3. 3   Effect Sizes of the Relationships

Table 3.3 is ordered by weighted mean correlation coefficients (weighted mean r) and shows the combined effect size-the strength of the relationships. One can notice that most performance measures are financial, which account for 8 out of 10. There are only two groups of practices correlated with non-financial performance measures. They are: "Action programmes" with non-financial measures and "HRM" with "Quality". In addition, the 16 articles provided 88 correlation coefficients, 71 of which employed financial performance measurement. Although many studies (Fisher, 1992 and Maskell, 1991) emphasised upon the importance of using non-financial measurement, financial measures were still used alone, perhaps because the non-financial performance are difficult to measure.

All the relationships show positive relationships according to the weighted mean correlation coefficients provided in table 3.3. However, it is possible that one of the reasons that all relationships show positive correlation is because researchers may be more likely to report the correlation coefficients with significantly positive rather than those with insignificantly positive or negative correlations. In addition, adjusting directions of the relationships before combining them in the meta-analysis (mentioned at section 3.3.2) is the other reason why all relationships show positive in table 3.3. For example, the positive relationship between "hostility" and "return" is because the higher degree of hostility was awarded lower value.

The combined correlation coefficient for each catalogued relationship has been tested for significance by a T-test. All the mean correlation coefficients ($\bar{r}$) of the relationships are significant at 0.1 percent level except for the mean correlation coefficient of the relationship between "diversification" and financial performance (measured by "Return"), which is not significant even at 5 percent level.

The last column of table 3.3 provides the percentages of the observed variances which are explained by the sampling-error variances. If the observed variance can be mostly explained by the sample-error variance, the residual variance which is

the observed variance less the sample error variance, will be very small. Pearlman et al. (1980) suggested that the relationship be considered unmoderated if 75 percent or more of the observed variance can be explained by the artefacts including sampling error, measurement error, and different in range variances. In the situation of this research in which only the sampling error variance has been removed from the observed variance, it will be more acceptable that the cut-off decreases from 75 percent to 60 percent (Perters et al., 1985). Using this rule of thumb, only 3 correlations out of 10 relationships reported in table 3.3 can be accepted as unmoderated by other variables, and one of these is the correlation between "Diversification" and "Return" which has been combined to show non-significant relationship. The correlation between "human resource management practices" and "quality" has 74 percent observed variance explained by the sampling error variance. This relationships can therefore be considered unmoderated by other variables.

The combined correlation of the relationship between "NPD" excluding R&D and "Growth" is a special case in which the observed variance is small enough (0.001) and the sampling error variance (0.0018) is bigger than the observed variance. Hunter et al. (1982, page 49) and Terborg et al. (1982) treated this situation as the 100 percent of observed variance which can be explained by sampling-error variance and accepted the correlation coefficient as effect size of the relationship. This relationship can also be considered unmoderated by other variables.

When the percentage of observed variance which can be explained by sampling-error variance is low, there may be other artefacts such as measurement error, computational error which influence the observed variance, or there may be influence by moderating variables (Gooding & Wagner, 1985). The fact that the data of studies included in the review were collected in different countries or different industries can be a reason for moderating variables. Therefore, the effect sizes of the relationships with low percentages of the observed variances which can be explained by the sampling error variances can not be accepted at this stage

for their general applications. In order to gain insight into this effect, we consider first the correlation between "size" and "financial performance", which table 3.3 shows that only 2.3 percent of the observed variance of the correlation between "size" and "financial performance" were caused by the sampling error. That means that this apparently substantial 0.534 effect size of the positive relationship between these variables is still unacceptable for its general application.

There are originally four correlation coefficients reported in published studies for this relationship (size and financial performance), but one with a large sample size (n = 42,339) and the other three sample sizes were 266, 64 and 30 respectively. If the four correlation coefficients were combined together, the weighted mean correlation coefficient would be nearly the same as the one with a huge sample size. In this case, the weighted mean correlation coefficient which was a combination of four correlation coefficients was -0.0475 and the correlation coefficient of the huge sample was -0.05. The other three correlation coefficients which were included in the meta-analysis were 0.78, 0.01 and -0.52 respectively. It is very observable that there is a huge variance among these coefficients. It also supports that there is only 2.3 % explained variance in this group. The research (Ito, 1993) with 0.78 correlation coefficient employed Japanese manufacturing firms as the sample and used "assets" measuring "size" and "domestic sale" as financial performance measure. The research (Richardson et al., 1985) with 0.01 correlation coefficient used the sample of Canadian electronics firms with "annual sales" as "size" and "profit" as financial performance measure. The research (Arthur, 1994) with -0.52 correlation coefficient was carried out for the US. steel minimills and "the number of employees" as "size" and "labour hours" as performance measure.

The reasons why these three correlation coefficients are so different may be that these three studies on the relationship between "size" and performance employed different measures and used different countries' manufacturing firms as samples. Therefore the percentage of the observed variance explained by sampling error

variance is very low. In fact, the population variance is very high for these three so different correlation coefficients. In this case, therefore, the observed variance of the weighted mean correlation coefficient could be caused by contextual moderating variables and/or other artefacts rather than sampling-error.

Other catalogued relationships in table 3.3 with low percentage of observed variances which can be explained by sampling error variance share the similar reasons. The combined correlation coefficient of the relationship between "NPD/R&D" and "Return" with 6.3 percent observed variance which can be explained by the sampling-error variance was a result of combining the data collected from two different countries, the American furniture industry and Japanese Manufacturing firms.

The correlation coefficient of the relationship between "focus" and "Return" with 1.9 percent observed variance explained was the combined results of studies whose data were collected from manufacturing firms in America and Canada. The correlation of the relationship between "HRM" and "Labour productivity" with 19.4 observed variance explained was composed of two different industries' data in US, an international data set from automotive assembly plants and steel minimills. The correlation of the relationship between "Age" and "Financial performance" with 44.1 percent observed variance explained combined studies whose data were collected from two different industries in US, steel minimills and manufacturing industry firms which had experienced acquisition. The correlation of the relationship between "Hostility" and "Return" (positive relationship between reducing hostility and return) with 26.3 percent observed variance explained was composed of 8 correlations from four studies which used the data from American manufacturing firms experiencing acquisition, steel minimills, international manufacturing firms and small manufacturing companies in US. The correlation of the relationship between "Action programmes" and "Non-financial performance" with 44.1 percent observed variance explained combined studies whose data were collected from American steel minimills, the European

manufacturing futures survey, international data set of automotive assembly plants.

Unfortunately, further investigations can not be conducted because of an insufficient number of published studies available for each manufacturing performance and practice relationship study. Even those that are published do not consistently provide the information which is required for further investigations. This must therefore be deferred pending further research when sufficient relevant information has been reported. Except for the information about reliability of the independent variables, the reliability of the dependent variables, and the range departure (mean and standard deviation of the variables) should also be published. The information makes not only the correction of sampling-error but also the corrections of errors of measurement and range variation possible (Hunter et al., 1982)

For the acceptable correlation coefficients, it is important for practitioners to properly understand what a correlation coefficient of a relationship means. There are different ways to interpret effect sizes for correlational studies. Traditionally, the square of the correlation coefficient was used as an estimate of the shared variance between the two variables that are correlated. Therefore, the three accepted relationships can be explained as follows. Implementing human resource management related programmes was responsible for 44.6 % variability on quality improvements. Implementing new product development had a 35.1 % increased opportunity on manufacturing companies' growth. Due to non-significance of the combined size of the relationship between diversification strategy and manufacturing return, it can be said that diversification strategies did not contribute manufacturing companies' performance measured by 'return'. Even though the non-significant effect was positive after combination by the meta-analysis, it only means that it occurred by chance because it is non-significant.

Rosenthal and Rubin (1982) provided a more intuitive, insightful, and perhaps useful way to evaluate the practical importance of correlation coefficients. This procedure is based on the mathematical transformation of a correlation coefficient (r) to a chi square (χ^2) and provides what Rosenthal and Rubin call a "binomial effect size display" (BESD) for 2×2 table (Rosenthal and Rubin, 1982, page. 167). The BESD is the estimated difference of percentage in success probabilities between treatment and control. In this study, it indicates the probabilities of manufacturing performance increased by implementing a certain practice. The procedure assumes that a causal link has been established by the survey or experimental design. More details of this interpretation are provided by Rosenthal and Rubin (1982) and Wolf (1986).

Independent variables	Dependent variables	Weighted mean r	Shared variance r^2	Perfo. Increased rate from	to	Percentage increased
HRM	Quality	0.446	0.20	0.28	0.72	44
NPD	Growth	0.351	0.12	0.32	0.68	36
Diversification	Return	0.094	0.01	0.45	0.55	10

Table 3. 4   Binomial Effect Size Displays for the Correlation Coefficients

Table 3.4 presents the BESD for the 3 groups' combined correlations with acceptance for general application. Even though the correlation between diversification and return is very low, which means that diversification and return have a non-significant relationship after the combination of the correlations by the studies on this relationship by the meta-analysis, the combined result is acceptable. The BESD seeks to show the difference in the likelihood of improved performance between those who adopt a practice and those who do not. According to table 3.4, the implementation of new product development is likely to significantly improve growth in 36% of cases, which is from 32% to 68%. Also, the probability of improving quality performance can increase an average 44%, which is from 28% to 72%, by implementing the HRM programmes.

3.6   Limitations of Meta-Analysis Results

"Meta-analysis, like most research methods, has certain inherent shortcomings; among these are publication bias, quality and other biases created by lack of controlled conditions, lack of statistical independence among studies and lack of homogeneous measure." (Capon et al., 1990).

Publication bias, such as some studies which did not report non-significant correlations, also affects the results of a meta-analysis. Results of research with non-significant and negative correlations may be less likely to be published than research reporting positive and significant correlations. Nevertheless, previous explorations of these types of problem indicate that they are unlikely to affect the basic conclusions of the meta-analysis (Sultan et al., 1989).

Two cautionary notes should be sounded. First, the approach cannot in itself demonstrate causality in the relationship between practice and performance, which depends more fundamentally on the survey design and the causality analysis approach taken in each study (Hamblin & Lettman, 1996). Second, the macro level findings cannot necessarily be applied to individual units, since the conditions for success may not be present.

3.7   Summary

In summary, the results of the two forms of meta-analysis present insight into the current research situation on the relationships between manufacturing performance and practice from different angles. The first form has identified the existence of a relationship after combination and has provided six good practices. At the second form, the effect sizes of the relationships have been combined and tested to have generated three acceptable relationships.

In addition, the meta-analysis highlights the very great diversity in outcomes of the relationship studies that have been published over the ten years. In spite of diversity of outcomes commencing with 23 practice categories and six groups of performance variables, generally applicable results are very few and far between.

The gaps discovered in this chapter form the basis for the future research issues. The details on the gaps are presented in chapter 5, which is about the research issues and methodological approaches. In this section, the useful information on the manufacturing practice and performance relationship gained from combining from the two forms of the meta-analysis is summarised.

The first approach, counting approach, generates the six good practices for manufacturing companies improving their performance, which appear to be:

(1) new product development;

(2) human resource management practice programmes;

(3) quality management programmes;

(4) flexible manufacturing system;

(5) long-term investment; and

(6) lean production.

Even though these six practices showed more likelihood of being related to improved manufacturing performance, caution is still needed in implementing them in an individual company. That is because the results of the meta-analysis are related to statistical probabilities, and do not provide a determinant or causal relationship. The results provide a reference for manufacturing companies to guide their choice towards improving their performance. It is always the case that the specific situation of an individual company needs to be investigated before identifying and implementing a "good practice".

The second form of the meta-analysis provides the three relationships that do not reject situational specification and their effect sizes can be applied in general. They are:

(1) significantly positive effect size of human resource management related programmes on "Quality" (44.6%);

(2) significantly positive effect size of new product development on "Growth" (35.1%);

(3) non-significantly positive effect size of diversification (product and geographic diversity) on "Return" (9.4%).

The relationships between manufacturing performance and practice have been reviewed and the results of individual studies have been combined from which the need for further investigation of manufacturing practice and performance relationships, especially for size of a relationship, is identified. The next step of this research should lead to propose research questions and construct methodological approaches that can be used to tackle the questions. In order to construct the methodological approaches, the methods that have been employed in the manufacturing practice and performance relationship studies and relevant knowledge need to be reviewed first. It is conducted in next chapter.

Chapter 4   Quantitative Methods used to Study Manufacturing Practice and Performance Relationships

4.1   Introduction

The published studies of the manufacturing practice and performance relationships (appendix 1) employed a relatively wide range of methods. Basically, the methods used for the relationship studies can be classified into qualitative and quantitative. Qualitative methods identify a relationship qualitatively and provide a tool to have an insight investigation of the relationship in a rich context, therefore the existence of a relationship is discovered. Quantitative methods test a relationship quantitatively – the size of a relationship uncovered based on a decent size of sample. Both qualitative and quantitative methods are effective in their own ways to study relationships, depending on the perspectives the researchers perceive and investigate and the information the researchers hold. Due to the characteristics of this research, which focuses on the exploration of the sizes of relationships, quantitative methods are more relevant.

Therefore, the methods that have been used to quantitatively evaluate the relationships between manufacturing performance and practices are reviewed in this chapter. Basic concepts and techniques related to quantitative methods for relationship studies are presented first in order to aid understanding of the quantitative methods reviewed in this chapter.

Most published research papers that quantified the relationships between manufacturing practice and performance only reported the results or the findings. The methods used in the studies were presented without reporting the procedures or processes of the methods. It is useful to investigate the process of a method. Whether or not the method that has been applied is suitable or complete for a certain research environment or situation is crucial in determining the validity of the results. If the method that has been employed is not suitable for that situation, the results of the research are invalid.

The most frequently used method in quantitative studies of manufacturing performance and practice relationships is regression analysis based on econometrics. However, when the studies focused on a relationship between a single practice factor and performance, correlation analysis was employed in most of the studies reviewed. In correlation analysis, the correlation coefficients between practice variables and performance variables or the correlation matrix between any pair of variables have been reported. Simple regression models were not provided in these studies with correlation coefficients investigated. For the studies researching joint effects of several practice factors on performance, different multiple regression models have been developed. Most studies using multiple regression analysis also reported the correlation coefficients between each pair of variables because these coefficients are fundamental for the models. Therefore, the review of the quantitative methods is simply divided into two parts, correlation analysis and multiple regression analysis. Certainly, multiple regression analysis includes many forms of models and the review of these models is provided in this chapter as well.

The main sections in this chapter, therefore, are:

1. Introducing basic concepts and techniques related to quantitative methods for relationship studies
2. Reviewing the applications of the methods used in manufacturing performance and practice relationship studies.

4.2   Basic Concepts and Techniques for Quantitative Relationship Studies

The fundamental concepts are defined through the introduction of techniques that are relevant to the quantitative methods used in the relationship studies, which are reviewed in the next section. The basic concepts related to correlation analysis are introduced first. Regression analysis, which is separated into the three topics (1) regression models, (2) regression procedure and (3) methods of estimating parameters of regression models, are presented subsequently. The detailed knowledge is available in books with topics such as statistics, regression analysis

and econometrics (Spiegel, 1972; Douglas, 1987, Draper and Smith, 1981; Dougherty, 1992 and Greene, 1993).

4.2.1   Correlation Analysis

Correlation analysis is a method in which the correlation coefficient between two variables on the two sets of data is calculated and analysed. This method deals with the relationship between two variables and seeks to determine *how well* a linear model or other equation describes or explains the relationship between two variables and *how strong* the relationship is. Correlation analysis investigates the degree of relationship without expressing this relationship in mathematical form by determining an equation between variables. Analysis related to determining an equation between the variables is described as regression analysis and is discussed in the next section.

The relationships between two variables can be linear (straight line) or non-linear (curve). Non-linear relationships between two variables can be polynomials (such as quadratic, cubic) or exponential or hyperbola or geometric functions and any other forms. As mentioned, correlation analysis investigates the degree of the strength of a relationship between two variables rather than building a model and estimating the parameters of the model.

If X and Y denote the observations of two variables, the total variation of Y is defined as $\Sigma(Y-\bar{Y})^2$, which consists of the explained variation ($\Sigma(Y_{est} - \bar{Y})^2$) and the unexplained variation ($\Sigma(Y-Y_{est})^2$). Y_{est} represents the estimated value of Y for given values of X using the estimated equation form. $\bar{Y}$ is the mean of the observations of Y. The ratio of the explained variation to the total variation is called the coefficient of determination. If the total variation is all unexplained, this ratio is zero. If the total variation is all explained, the ratio is one. In other cases, the ratio lies between zero and one. The ratio is denoted by r^2 because it is always non-negative. The quantity r is called the correlation coefficient. The value of r is from -1 to 1. The signs $\pm$ are used to represent positive or negative correlations. The closer the value of r is to ± 1, the more highly correlated the two variables

are. Correlation analysis can be conducted without estimating the equation form between two variables if the relationship between them is assumed as linear, which is often used. It can be easily understood through inspecting the formulae of r.

A general formula for calculating correlation coefficients is given below:

$$r = \pm \sqrt{\frac{\sum (Y_{est} - \bar{Y})^2}{\sum (Y - \bar{Y})^2}}$$
(4.1)

A linear relationship has been used mostly for two variables. When the linear relationship between the two variables is assumed, it is unnecessary to construct a model and resolve the parameters of the model as well as estimate the values of dependent variable (Y_{est}) to obtain correlation coefficients of the two variables. We can tell from the formula in which a linear relationship between two variables is assumed:

$$r = \frac{\sum xy}{\sqrt{(\sum x^2)(\sum y^2)}}$$
(4.2)

where $x = X - \bar{X}$ and $y = Y - \bar{Y}$

It is called the product-moment formula or Pearson's correlation coefficient that is used for two variables that are continuous. A short computational formulae for (4.2) is also available:

$$r = \frac{N \sum XY - (\sum X)(\sum Y)}{\sqrt{[N \sum X^2 - (\sum X)^2][N \sum Y^2 - (\sum Y)^2]}}$$
(4.3)

When two variables are not continuous and can not measured by precise values, which is often the case for variables in management studies, a different formula

has to be used to obtain a more accurate correlation coefficient between them. These variables may be ranked in order of size, importance, etc., using the number 1, 2, ..., N, instead of using precise values of the variables. If two variables X and Y are ranked in such a manner the coefficient of rank correlation is given by

$$r = 1 - \frac{6 \sum D^2}{N(N^2 - 1)} \qquad (4.4)$$

where D = differences between ranks of corresponding values of X and Y

N = number of pairs of values (X, Y) in the data.

It is also called Spearman's formula for rank correlation.

The correlation coefficient can be used to indicate whether two variables are associated with each other. If it is significantly different from zero, it shows there is a relationship between these variables and also it represents the strength of the relationship. However, the relationship between these variables remains unknown if the model between them is not built and the parameters in the model are not estimated. When a linear relationship is assumed, Pearson's or Spearman's formulae should be considered. When the variables are continuous, Pearson's correlation formula is used. When the variables are ordered in ranks, Spearman's rank correlation formula is used. However, the equation between these variables is unknown if only correlation coefficient is calculated. In practice, it is useful to know the estimates of the parameters in the model and analyse the outcomes and the relationships discovered. This can be conducted using regression analysis.

In the following sections, the three topics on regression analysis, which are relevant regression models, procedures to build a model and the methods that are available to be used to estimate the parameters of a model, are presented subsequently.

4.2.2   Regression Models

Regression models are the equations built to be used to analyse relationships between variables using regression analysis techniques. It is an important part of regression analysis. Regression analysis is a statistical technique which includes model construction, parameter estimation and using the constructed model to analyse relationships, or for prediction. It is used to discover the apparent dependence of one variable upon one or more other variables. Regression analysis involving only two variables is called simple regression analysis; otherwise it refers to multiple regression analysis. Correspondingly, regression models can be simple regression models or multiple regression models.

Before introducing regression models, one issue needs to be clarified. It must be stated that a relationship between variables in regression analysis is not a determinant relationship and it is really only an approximation. Therefore, a model used to describe the relationship has to include a disturbance term (also called error or residual of the regression model) to make the equation balanced. In this section, relevant regression models are briefly described below.

Regression models can be simply classified into linear or non-linear regression models. Linear models can be further divided into simple linear models and multiple-linear models. Non-linear models can take many forms and details are given in this section.

Simple linear model

A simple linear regression model involving a single independent variable (x) is given by

$$y = \alpha + \beta x + \varepsilon \tag{4.5}$$

α and β are parameters of the model and ε is the disturbance term. α is also called the constant of the model.

When a linear relationship is hypothesised for an independent variable x and a dependent variable y, the above simple linear regression model can be used to test the hypothesis using the data collected for variables x and y.

Multiple linear model

Having hypothesised that y is a function of several x variables in a linear relation, a multiple linear regression model can be used and is given by

$$y = \alpha + \beta_1 x_1 + \beta_2 x_2 + ... + \beta_n x_n + \varepsilon \qquad (4.6)$$

This model can be used when a multiple linear relationship between several independent variables x_i and a dependent variable y is proposed.

Non-linear model with one independent variable

In the view of management, a simple model is preferred. Therefore a linear model is suggested to be considered first only if the literature suggests a possible non-linear relationship between investigated variables. When the relationship to be investigated involves only two variables, a scatter diagram, which is a plot of points representing a series of observed relationships between two variables, of these two variables using the data sample can generate an idea to hypothesise the relationship. Possible non-linear regression functions involving a single independent variable which have been mentioned in econometrics or economics practice are listed as follows.

(1) A polynomial regression model is given by

$$y = \alpha + \beta_1 x + \beta_2 x^2 + ... + \beta_n x^n + \varepsilon \quad (n \neq 1) \qquad (4.7)$$

If n = 2, 3, 4, the model is called quadratic, cubic, and quartic functions respectively. The equation with n higher than 4 is fairly rarely employed in

practice. It is noted that the model becomes a simple linear model if n is equal to 1.

(2) An exponential regression model is given by

$$y = \alpha \, \beta^x \, \varepsilon \qquad\qquad (4.8)$$

(3) A geometric regression model is given by

$$y = \alpha \, x^{\beta} \, \varepsilon \qquad\qquad (4.9)$$

(4) A hyperbola regression model is given by

$$y = \alpha + \beta / x + \varepsilon \qquad\qquad (4.10)$$

Certainly, there are other forms of non-linear regression models with one independent variable involved which can be used to construct a relationship between two variables. They can not be listed exhaustively in this research.

Non-linear model with more than one independent variables

When a relationship involves more than one independent variable, a scatter diagram can not be drawn in a two-dimensional plane, and therefore, the relationship can not be observed directly. In this case, the relationship is hypothesised mainly according to the literature's suggestions with the assistance of common sense.

(1) A power function model is given by

$$y = \alpha \, x_1^{\beta_1} x_2^{\beta_2} \varepsilon \qquad\qquad (4.11)$$

The power function is the most commonly used non-linear model with more than

one independent variable in economics and econometrics. When $\beta_1 + \beta_2 = 1$, the above function converts into the famous function called the Cobb-Douglas Production Function. In the Cobb-Douglas function, x_1 and x_2 represent capital input and labour input and y stands for output. This specific form of power function $(\beta_1 + \beta_2 = 1)$ has been applied in many relationships in practice to reach a goodness of fit for the collected data on investigated variables.

(2) Multiplicative interaction model

When two or more independent variables interacting with each other affect a dependent variable, a multiplicative interaction model, in short interaction model, should be considered. When the effect of an independent variable on a dependent variable is influenced by another independent variable, the interaction effect between these two independent variables on the dependent variable is possible. An interaction model is formed through including a product term of two or more independent variables in a multiple-linear model. It is not a complicated form of regression models. However it has only been applied in a few cases in practice due to several issues which need to be solved during the model estimation process.

A basic interaction model with a multiplicative interaction term of two independent variables is given by

$$y = \alpha + \beta_1 x_1 + \beta_2 x_2 + \beta_3 \, x_1 \times x_2 + \varepsilon \qquad (4.12)$$

The above model is also called a two-way interaction model because it involves a two-independent variables' interaction term $(x_1 \times x_2)$.

When the literature suggests that there is possible a three-independent variables' interacting influence on a dependent variable, a completed three-way interaction model is given by

$$y = \alpha + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3$$
$$+ \beta_4 x_1 \times x_2 + \beta_5 x_2 \times x_3 + \beta_6 x_1 \times x_3$$
$$+ \beta_7 x_1 \times x_2 \times x_3 + \varepsilon \qquad\qquad (4.13)$$

An interaction model could be built in a four-way or more than four ways' interaction, but it would be too complicated to be applied in practice.

It is necessary to introduce the two types of variables that are relevant to interaction models. They are control variables and moderator variables.

Control variables in interaction models are the independent variables without involving the interaction with other independent variables. A simple interaction model with one control variable is given by

$$y = \alpha + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_4 x_1 \times x_2 + \varepsilon \qquad\qquad (4.14)$$

Obviously, x_3 is a control variable. The number of control variables can be varied according to the factors that are taken into account in a study and the characteristics of the factors for a certain situation. It is not necessary to include a control variable in an interaction model.

If one of the interacted independent variables is hypothesised as having a moderating role for the relationship between other independent variables and the dependent variable, the variable is called a moderator variable and the regression analysis is called the moderated regression analysis (Covin and Slevin, 1989). In model 4.12, one of the independent variables (x_1 or x_2) can be hypothesised as a moderator variable, for example x_2. The effect of x_1 on the dependent variable is mainly studied to form a basic regression model. The moderator variable x_2 then enters the basic model in an interacting form with variable x_1 to test its moderating influence on the relationship between x_1 and y. In this case, the whole analysis involves two steps. The first step excludes the moderator variable (certainly without the interaction term). The moderator variable and its interacting effect

with the other independent variable then add into the first step's model. If the power of the moderated regression model (r^2) is increased significantly, the moderating role of the moderator variable is supported.

For the interaction regression models without hypothesised moderator variables, the use of a stepwise fashion is also suggested. The difference from the moderated stepwise regression is that both of the two independent variables are included in the first step model, if the model only includes two interacting variables. Then, their product term enters the step 1 model to test whether there is an interaction effect of these two independent variables on the dependent variable. If the addition of the interaction term significantly increases the power of the regression equation to explain the variance in the dependent variable, the interaction model is suggested to have a better model specification and the interaction effect is supported. Therefore, when literature suggests that there may be an interacting effect between two independent variables, the models including and excluding the interaction term should be constructed in order to compare the results of the two models to draw conclusions.

Transformation of non-linear models

So far, linear models or non-linear models in their original forms have been presented. Because the method used to estimate parameters in linear models is much simpler and more straightforward than the methods used for non-linear models, transformations of non-linear models into linear models have been concerned. If it is possible, non-linear models are desired to be transformed into linear models.

Some of the non-linear models mentioned in this section can be transformed into linear models and therefore, linear regression analysis can be applied. There are two different non-linear models. One is non-linear in variables but linear in parameters, such as polynomial functions and hyperbola functions. The other is non-linear both in variables and in parameters, such as exponential functions,

geometric functions and power functions.

For functions with non-linear in variables but linear in parameters, a transformation of variables is easy to undertake simply by using appropriate definitions.

For the hyperbola function *(4.10)*, it can be rewritten into a linear model by defining $z = 1/x$

$$y = \alpha + \beta z + \varepsilon \qquad (4.15)$$

The same method can be applied supposing that the relationship were of the form

$$y = \alpha + \beta_1 x_1^2 + \beta_2 \sqrt{x_2} + \ldots + \varepsilon \qquad (4.16)$$

By defining $z_1 = x_1^2$, $z_2 = \sqrt{x_2}$, etc.; the relationship can be rewritten

$$y = \alpha + \beta_1 z_1 + \beta_2 z_2 + \ldots + \varepsilon \qquad (4.17)$$

The same process can be used for polynomial functions. Then linear regression techniques can be used to estimate the parameters by regressing y against z. A reversed process can be applied afterwards for replacing z by x.

For the functions that are non-linear both in parameters and in variables, logarithmic transformation may be applied to transform them into linear models.

The exponential function *(4.8)* can be transformed into a linear model in variables by taking logarithms of both sides:

$$log\, y = log\, \alpha + (log\, \beta)\, x + log\, \varepsilon \qquad (4.18)$$

By defining $y' = logy$, $\alpha' = log\alpha$, $\beta' = log\beta$ and $\varepsilon' = log\varepsilon$, the function *(4.18)* can be rewritten into a simple linear equation:

$$y' = \alpha' + \beta'x + \varepsilon' \qquad\qquad (4.19)$$

Therefore, a linear regression analysis can be applied to estimate parameters α' and β'. By taking an anti-log of α' and β', original parameters α and β can be restored.

The power function *(4.11)* can also be linearised by taking logarithms of both sides:

$$logy = log\alpha + \beta_1 logx_1 + \beta_2 logx_2 + log\varepsilon \qquad\qquad (4.20)$$

Function *4.20* is transformed into linearity in parameters. By defining $y' = logy$, $\alpha' = log\alpha$, $x_1' = logx_1$, $x_2' = logx_2$ and $\varepsilon' = log\varepsilon$, function *4.20* can be rewritten into a multiple-regression model:

$$y' = \alpha' + \beta_1 x_1' + \beta_2 x_2' + \varepsilon' \qquad\qquad (4.21)$$

It is noted that parameters β_1 and β_2 remain unchanged during the transformation. Therefore, β_1 and β_2 do not need any reversing process after parameters α', β_1 and β_2 have been estimated. Only parameter α needs to be reversed by taking anti-log of α'. The Geometric function *(4.9)* is a simple form of the power function with one independent variable. The same transformation process therefore can be applied to the geometric function.

Regression models with dummy variable(s)

Sometimes a factor, which may be worthwhile to introduce into a regression model, is qualitative in nature and is therefore not measurable in a numerical format. If we need to know whether the factor makes a difference to the

relationship between the existent dependent variable(s) and the hypothesised dependent variable, one solution is to build two different models to run two separated regressions for the two categories and see if the coefficients are different. Alternatively, a dummy variable can be employed to represent the factor and a single model can therefore be used for solving the problem. When a dummy variable is used, the factor is measured using two values, value 1 when the factor occurs; otherwise 0. It has two important advantages. Firstly, it provides a simple way of testing whether the effect of the qualitative factor on the dependent variable is significant. Secondly, provided that certain assumptions are valid, it makes the regression estimates more efficient.

Dummy variables are allowed to enter different kinds of models. A simple linear model including one dummy variable and one normal independent variable is given for illustrative purposes.

$$y = \alpha + \beta x + \delta D + \varepsilon \qquad (4.22)$$

Where D is a dummy variable with only two possible values 0 and 1 for correspondent x values. If coefficient δ is significant from zero, the effect of the factor represented by the dummy variable on the dependent variable is supported.

Probit function

The probit Equation is used for explaining a binary (0/1) dependent variable, (compared with a dummy variable, which is a binary independent variable). The sum of the probability of obtaining value 0 and the probability of obtaining value 1 is equal to 100%. When data on dependent variables are only available in binary format (e.g. survival or failure) or only the binary results of dependent variables are interesting for analysts, a probit regression model can be used.

Lag structure regression models--with time series or panel data

So far, the models presented are used to investigate the relationships between variables without time delay, or in other word, the variables are collected for the same time period. Such an assumption is built in when cross-sectional data are used, where a sample is taken from a population of individuals. When a delay effect between factors needs to be investigated, a set of time series data on these variables needs to be collected first. A data set that is cross sectional and time series is called panel data. With panel data, the delay effect between factors can be explored using a model in lag structure.

Using a simple linear regression for illustrative purposes, the model, which is regressed on the two variables within the same time period, is given by

$$y_t = \alpha + \beta x_t + \varepsilon \qquad\qquad (4.23)$$

Subscript t attached to the variables represents the time periods in which the data on the variables are collected. In model 4.23, the data on the dependent and independent variables represent the same period, which means that no delay effects are considered. When the delay effect of the independent variable on the dependent variable by s years is suggested, the model becomes:

$$y_t = \alpha + \beta x_{t-s} + \varepsilon \qquad\qquad (4.24)$$

Time periods are investigated or measured normally by years in practice. In most cases, the number of delayed years is unknown and needs to be discovered for the delay effect between variables. It can be conducted by giving s values of 1, 2, 3 ...., n. The number of years of delayed effect between variables therefore can be discovered by comparing the model results in different delayed years (lagged years). When the effect of an independent variable on a dependent variable may occur in a number of lagged years, not just in a single lagged period, the model can be constructed by using the same independent variable several times in the

same equation with different lags. The following model represents one of this kind of relationship.

$$y_t = \alpha + \beta x_{t-1} + \beta x_{t-2} + ... + \beta x_{t-s} + \varepsilon_t \tag{4.25}$$

Technically, the above lag structure model is called a distributed lag model, for the effect of a unit change in the value of the explanatory variable (independent variable) is spread over, or distributed over, a number of time periods.

There are other types of lag models, for example, the model with a lagged dependent variable. In this kind of model, the dependent variable, lagged for one or several periods, is used as one of the explanatory variables. The model with the dependent variable lagged for one period is given by

$$y_t = \alpha + \beta_1 x_t + \beta_2 y_{t-1} + \varepsilon_t \tag{4.26}$$

The lagged model is valuable when the relationship is hypothesised involving a delay effect between variables. A lag variable can be added into different types of models according to the hypothesis constructed.

4.2.3   Regression Procedures

Regression procedure is a way in which regression models are built. A model can be constructed including all variables concerned at a single step. In this case, the model construction does not involve steps. All independent variables which are hypothesised are directly used, and there is no more consideration for further selecting independent variables which should be included or excluded in the model. Besides, other two procedures are introduced in this section, which have been used in practice for selecting variables in order to build a better regression model. They are (1) the backward elimination procedure and (2) the stepwise regression procedure.

There is no "best" procedure to build a "perfect" model, which includes all the

variables which should be included and excludes all the variables which should be excluded. There is no perfect model specification for a relationship. It may be straightforward to exclude the variables that should not be included but it is impossible to include all the variables that should be included. In practice, the investigation into a relationship is carried out for the variables concerned.

In general, there are two criteria for developing a model:

1. In order to make the model useful and determine reliable fitted values of the dependent variable, as many independent variables as possible which may influence the dependent variable should be included in the model.

2. Because of the costs involved in obtaining information on a large number of variables, the model should include as few variables as possible.

The compromise between these extremes usually refers to as selecting the best regression equation.

The Backward Elimination Procedure

The backward elimination method begins with the largest regression, using all variables, and subsequently reduces the number of variables in the model until a decision is reached on the model to use. The basic steps in the procedure are (Draper and Smith, 1981):

1. A regression model containing all variables is computed.
2. The partial F-test value is calculated for every independent variable treated as though it were the last variable to enter the regression model.
3. The lowest partial F-test value, F_L say, is compared with a pre-selected significant level F_0, say.
    a. If $F_L < F_0$, remove the variable related to F_L, which gave rise to next F_L, from consideration and re-compute the regression model in the

remaining variables: re-enter stage 2.

b.   If $F_L > F_0$, adopt the regression model as calculated.

In some of the programmes, a t-test on the square root of the partial F-value is used instead of the F-test. It should reach the same conclusion.

This can be a satisfactory procedure due to no any missing variables from the start. However, if the input data yield an $X'X$ matrix which is ill conditioned, that is, nearly singular, because of the high correlation between the variables, then the over-fitted equation may be nonsense. In addition, when one a variable is eliminated, it is gone forever.

The Stepwise Regression Procedure

The stepwise selection procedure is an attempt to achieve a similar conclusion as the backward elimination procedure does but working from the other direction, that is, to insert variables in turn until the regression equation is satisfactory.

In stepwise regression analysis, a correlation matrix between the dependent variable and independent variables and two-tailed probabilities of these correlation coefficients should be computed first. Based on the criterion, that "each independent variable was allowed to enter the model providing its incremental r^2 was significant at $p<0.10$" (Fowler and Schmidt, 1989, page 345), only one independent variable, which meets the criterion, enters the model at each step. The independent variable chosen to enter the model has the highest correlation with the dependent variable in the group variables, which are not yet in the equation. It supposes to have the best increase in r^2. The independent variables with non-significant correlation coefficients with the dependent variable are omitted from the model eventually.

Some stepwise programmes re-compute the partial correlation coefficients of all independent variables with the dependent variable at each step, which are not yet

in the regression model, instead of using the original correlation coefficient matrix. However, the conclusion should not be different.

Mostly a stepwise regression analysis refers only to a multiple linear model in steps. If other types of models are built in step by step to increase R^2 of the model, they can be called a regression analysis in a stepwise fashion, such as the interaction model mentioned previously.

This method has been used more frequently than the backward elimination procedure in practice. It avoids working with more X's than are necessary while improving the equation at every stage.

4.2.4   Estimation Methods

After the model has been specified and relevant data are collected, the next stage is to estimate parameters of the model. The two methods, which are very common in use, are mainly introduced in this section. They are Ordinary Least Squares (OLS) method and Maximum Likelihood (ML) estimation.

Ordinary Least Squares (OLS)

It is the most common used method for linear models including the models that are transformed from non-linear models. Provided that the Gauss-Markov conditions for the disturbance term are satisfied, the OLS regression coefficients will be the best linear unbiased estimators (Dougherty, 1992).

Gauss-Markov conditions are concerned with the assumptions on the disturbance term. There are four conditions. Condition one is that the expected value of the disturbance term in any observation should be 0. Actually, if a constant term is included in the linear regression model, it is usually reasonable to assume that this condition is satisfied automatically. The second condition is that the variance of the disturbance term should be constant for all observations. Sometimes it may be greater or sometimes it may be smaller, but it is purely due to randomness rather than a priori reason. The third condition states that there should be no systematic

association between the values of the disturbance term in any two observations. The last condition is that the disturbance term should be distributed independently of the explanatory variables. This means that there are no significant correlations between the disturbance term and the explanatory variables.

When these four conditions are satisfied, OLS provides valid estimators of the parameters in linear models. Using a simple linear regression model for illustrative purposes, OLS minimises the sum of the squares of the residuals to find the best fitted line of the observations (data). If ε_i represents the residual for observation i and S for the sum of the squares of the residuals for all the observations, OLS minimises S.

$$S = \sum \varepsilon_i^2 \qquad (4.27)$$

The size of S will depend on the choice of α and β in the simple linear function (4.5) because they determine the position of the line. In the simple linear equation, S is minimised when

$$\beta = \frac{Cov(x, y)}{Var(x)} \qquad (4.28)$$

and

$$\alpha = \bar{y} - \beta \bar{x} \qquad (4.29)$$

It follows the same principle when dealing with multiple-linear regression models. The OLS method minimises the sum of least square of all the residuals to fit a best model by estimating coefficients in the model. In simple linear regression, the model can be illustrated by a straight line in a two-dimensional plane. The formulae to calculate the coefficients of the multiple linear regression model are provided in most regression computing packages.

Maximum Likelihood

When the models can not be built in linear and can not be transformed into linear models, OLS estimators will not be valid because the Gauss-Markov conditions will not be satisfied in most non-linear models. Maximum Likelihood estimation is the method which can be used for this situation. In principle, ML chooses parameter estimates to maximise the likelihood (probability) of the occurrence of the sample. Using a very simple example, a continuous random variable with unknown mean μ and standard deviation known to be equal to unity and the variable can be assumed to be normally distributed. If the variable has one observation x_1, the ML principle is that the hypothesis should be chosen that gives x_1 the highest probability of occurring. By working on the probability density function of x in a normal distribution, the best function for the variables with one observation is $y = x_1$, obviously. It can also be deduced from the density function by the ML principle (Dougherty, 1992, page 349).

The ML approach can also be used in linear models for estimation. However, there are four reasons for caution when using ML. Firstly, the ML approach intends to obtain better estimators for large samples rather than small samples. Secondly, ML is not unconditional of the properties of consistency (Dougherty, 1992, page 27-28) and asymptotic efficiency (Greene, 1993, page 305). Thirdly, it has to be assumed that the error terms have a particular asymptotic distribution; customarily, the normal distribution. Finally, ML estimation is often time-consuming in its application. Estimates often have to be derived by solving a system of simultaneous equations using an iterative procedure because they cannot be expressed as explicit mathematical formulae. However, nowadays the ML estimation is available in most regression computing packages, which makes the application of ML much easier.

Other Estimation Methods

There are other estimation methods available, such as Indirect Least Squares (ILS), Instrumental Variables (IV), Two-Stage Least Squares (TSLS) and

generalised least square (GLS). The first three methods mainly deal with simultaneous equations and GLS is an estimator which can be applied for seemingly unrelated regression equations.

If an independent variable in one of the set of equations is also a dependent variable in a different equation in the set, the model is treated as simultaneous equations. In other word, simultaneous equations include a set of equations (mostly two) with variables affecting each other in the different equations. If these equations include a group of related variables, which do not affect each other in the different equations, the set of equations can be treated as seemingly unrelated regression equations. The details of the two types of equations are given below.

When one of the independent variables in the model is actually not independent and decided by another factor or factors, simultaneous equations are applied. An example of simultaneous equations including two equations is given below:

$$C = \alpha + \beta Y + \varepsilon \qquad (4.30)$$

$$Y = C + I \qquad (4.31)$$

In the above equations, C is a dependent variable in equation 4.30 but also an independent variable in equation 4.31 and Y is an independent variable in equation 4.30 but a dependent variable in equation 4.31. Actually, variables C and Y are endogenous variables, whose values are determined inside the model. Only variable I can be independent or called an exogenous variable, where the value is determined outside the model and therefore taken as given. If we try to estimate α and β by regressing C against Y using OLS directly, the estimates of the coefficients will be biased and the standard errors will be invalid. It is because Y is actually correlated with the disturbance term ε and therefore, the fourth Gauss-Markov condition is violated. It can be identified by lookng at the reduced equation on Y, in which only the exogenous variable is included in the right side of the reduced model.

$$Y = \frac{\alpha}{1-\beta} + \frac{I}{1-\beta} + \frac{\varepsilon}{1-\beta} \qquad (4.32)$$

Moreover, the reduced equation for C is given, which is the main concern in the two equations.

$$C = \frac{\alpha}{1-\beta} + \frac{\beta I}{1-\beta} + \frac{\varepsilon}{1-\beta} \qquad (4.33)$$

Therefore, the coefficients in equation 4.33 can be estimated by regressing C against I, which is an exogenous variable and is very unlikely to be correlated with the disturbance term. The obtained estimates of the coefficients of $\alpha/(1-\beta)$ and $\beta/(1-\beta)$ can be converted into the estimates of the coefficients of α and β. This method is called ILS.

There are other methods that can be used for the estimations of simultaneous equations. One of the methods is the instrumental variables (IV) technique. Using IV, the estimate of the coefficient β is given below.

$$b_{IV} = Cov(I,\ C)\ /Cov(I,\ Y) \qquad (4.34)$$

Where Cov (I, C) is the covariance between I and C and Cov (I, Y) is the covariance between I and Y. The estimates of α and β using IV should reach the same results using ILS.

If the number of equations in simultaneous equations are more than two, the method which is called two-stage least squares (TSLS) can be applied. The two stages are:

1. Regress the reduced form equations and calculate the predicted values of the endogenous variables.
2. Use the predicted values as instruments for the actual values, then use the IV

technique; or, use the predicted values of the endogenous explanatory variables instead of their actual values in an OLS regression.

As far the seemingly unrelated regression model is concerned, the generalised least squares method can be applied. The seemingly unrelated regression model includes a set of equations and its basic form is given below.

$$y_m = X_m \beta_m + \varepsilon_m \tag{4.35}$$

Model 4.35 consists of m equations. X_m, β_m and ε_m are vectors with m factors. Instead of using OLS for equation by equation, GLS provides the estimates for the equations efficiently by generating a covariance matrix of the disturbance term to work out the coefficient vector of β_m (Greene, 1993, page 488).

Simultaneous equations and seemingly unrelated regression are rarely used in manufacturing practice and performance relationship studies.

4.3   Applications of the Quantitative Methods used in Manufacturing Performance and Practice Relationship Studies

In section 4.2, the concepts and techniques that are fundamental to gain understanding of the methods used in the quantitative relationship studies have been provided. In this section, the applications of these techniques on the relationships between manufacturing performance and practice are reviewed. Chapter 3 analysed 16 studies, which employed a range of quantitative methods used in the manufacturing practice and performance relationship studies. The methods used in these 16 studies are the resources for this section.

This section is organised under the two main headings, correlation analysis and multiple-regression analysis. Multiple-regression analysis applications are further divided into multiple linear regression analysis (excluding the applications using stepwise regression analysis), multiple interaction regression analysis and multiple log transformation regression analysis. In addition, stepwise multiple-regression

analysis, which is often employed to build a better multiple-linear regression model as a model building procedure, is listed separately as a sub-section. The applications using the stepwise multiple-regression analysis to build multiple-linear models are included in this sub-section. The other applications on multiple-linear regression analysis without using stepwise regression procedure are listed under the multiple-linear regression analysis. The reason to list stepwise regression analysis separately from the multiple linear regression analysis is because sufficient emphasis has been paid to the stepwise regression procedure to build a multiple-linear regression model and its applications in the literature.

4.3.1   Correlation Analysis

Correlation analysis was employed not only for studying a relationship between a single practice factor and a performance variable, but also for initially analysing the variables concerned to be built into a multiple-regression model. However, it was not always the case that correlation analysis has been conducted before building a multiple-regression model in practice, even through it does help and is actually an essential part of the model construction. In the applications of correlation analysis reviewed, correlation coefficients between two variables, one for practice and one for performance, or a correlation matrix between each pair of variables, no matter whatever the performance or practice, have been reported. However, simple regression models were not concerned in these applications, hence the exact relationship between the two variables remains unknown.

As mentioned in the last section, a rank correlation coefficient (Spearman's formula for rank correlation) can be used when it is difficult to obtain precise values of the variables, or such precision is not available. In such cases, the data for the practice activities and performance measures may be ranked according to importance or order of size, using the numbers 1, 2, ..., N, which has been also applied to some of the manufacturing practice and performance relationship studies.

Calantone et al (1995) correlated the importance of New Product Development activities using a 7-point scale from 'least important' valued 1 to 'extremely

important' valued 7 with the ranked overall business performance (six measures have been used) also using a 7-point scale with end points 'worst in industry' valued 1 and 'best in industry' valued 7. In his article, he only reported the correlation coefficients of performance in each activity with each of the six business performance measures. What kind of correlation (e.g. linear or rank) has been used was not mentioned in his paper. Therefore, the rank correlation was assumed to have been used in his study.

Fowler and Schmidt (1989) reported the correlation coefficient matrix between the six independent practice variables and the two performance variables. Based on the correlation coefficient matrix, the stepwise multiple-regression analysis has been conducted.

Bao and Bao (1989) reported the correlation coefficients between the six independent variables and the performance variable measured by firm value for the years 1979 to 1985. The multiple linear regression models have also been developed.

Macduffie (1995) reported the correlation coefficients between the performance variables and the practice factors. The two-way and three-way interaction regression models were developed based on these correlation coefficients.

Ito and Pucik(1993), Chaganti and Damanpour (1991), Richardson et al (1985) and Arthur (1984) reported a correlation matrix between each pair of variables, disregarding performance or practice variables, as the basic results of their studies and the further regression models have also been developed.

Carpano et al. (1994) reported the correlation matrix between variables, disregarding performance and practice, and used a t-test to identify the difference of the means of performance index between the two groups employing different strategic practices.

It is noted that the applications of correlation analysis alone in the studies of manufacturing practice and performance relationships are very few. Correlation analysis has been widely used as a means for the preparation in further establishing manufacturing practice and performance relationships.

4.3.2   Multiple-Regression Analysis

In order to classify and present the different multiple regression analyses which have been used in the literature on the manufacturing relationships between practice and performance, a priority flow chart has to be designed and used. This is because some multiple regression analyses possess more than one feature, for instance, interaction and log. When this happens, the model possessing both interaction and log has to be classified either into the interaction model group or the log transformation model group. According to the priority flow chart, which is given below, the decision can be made.

Multiple Regression Analysis Models
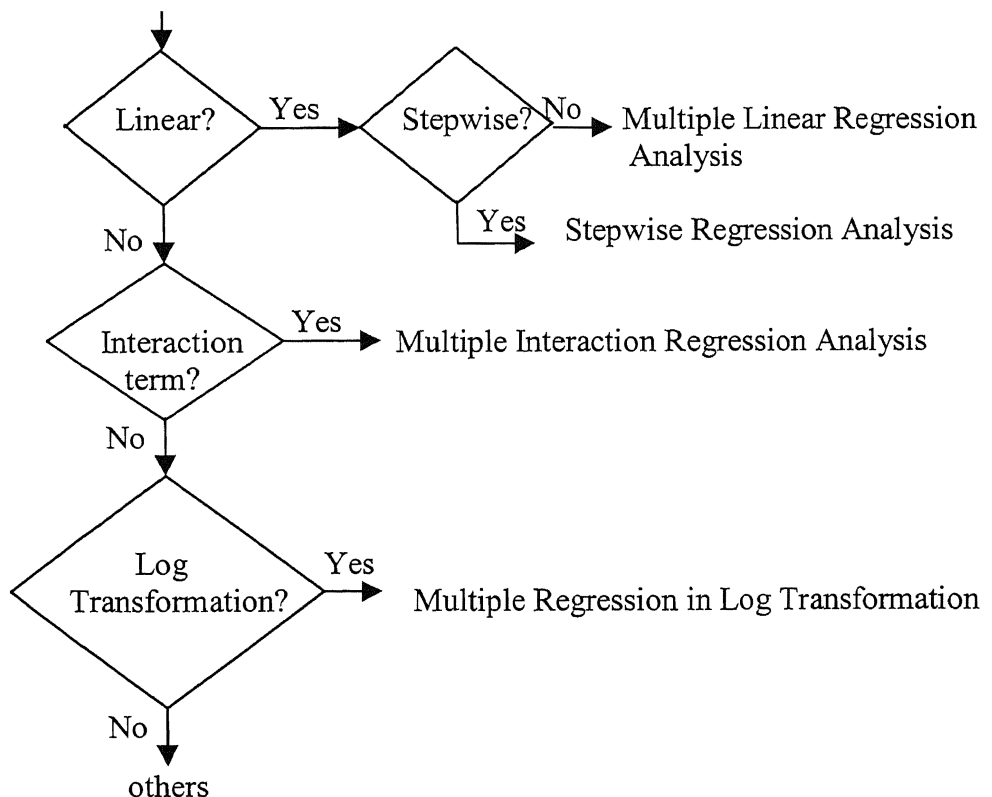
Figure 4. 1   The Priority Flow Chart for Classifying Multiple Regression Analysis Applications in Manufacturing Practice and Performance Relationships

When the relationships which have been studied involved more than one practice factor, the following four types of multiple-regression models have been used in the literature.

1. Multiple Linear Regression Analysis (standard)

A general model for multiple linear regression has been given in function *4.6*. An application by Garsombke and Garsombke (1989) involved three practice factors regressed against performance measured by three variables in three individual multiple linear regression models. The three models are generally the same but consist of different performance variables. The model, in which performance is presented in a general term, is:

$$Performance = \alpha + \beta_1 Robotics_i + \beta_2 Automation_i + \beta_3 Computerization_i$$

Three performance measures which have been used in this research are overall performance (the total number of performance effects checked), throughput performance (the total number of throughput variables checked) and output performance (the total number of output variables checked). The value of an independent variable is the number of technologies in each catalogue that has been employed in each company included in the sample.

This research did not report the correlation coefficients between the variables and the inter-item reliability of the variables. It is possible that these three explanatory variables are strongly correlated because they are all measures for the use of technology. The strong correlations between one element of the variable (computer accounting system) and other elements as well as the overall system have been reported by the authors. Therefore, a problem caused by highly correlated independent variables, which is called multicollinearity influencing the accurate estimations, could occur in this research. However, whether multicollinearity is a problem for the regression models has not been discussed in

this paper.

Richardson et al. (1985) developed a multiple linear regression model with three independent variables. The three independent variables were chosen based on the correlation matrix that included the five investigated practice variables which could have an effect on performance. Because of high correlation between each of the three chosen practice variables and the performance variable, a multiple linear regression model including these three independent variables was constructed against the performance variable. In addition, multicollinearity was not a problem because of low correlation between each pair of these three independent variables. The model was:

$$PROFIT = \alpha + \beta_1 CFOCUS + \beta_2 CHIGH + \beta_3 COST + \varepsilon$$

Where CFOCUS represented corporate focus, which was measured by the sum of squared error from the least fit profile, CHIGH was a dummy variable used to represent the congruency score between the mission and the task.

Chang and Thomas (1989) constructed a model that consisted of two regression equations. One of the two equations used six explanatory variables including two dummy variables regressed against 'Return' in a multiple linear equation. The other equation used 'Risk' as a dependent variable in a curvilinear relationship with 'return' and other factors related to diversification strategies as independent variables. The linear equation was specified as:

$$RETURN_i = b_0 + b_1 WIRN_i + b_2 SIZE_i + b_3 NB_i + b_4 RL_i + b_5 UR_i + b_6 RISK_i + \varepsilon_i$$

Where RETURN represents corporate return of firm i measured by the mean of RoA over the 5-year period (1977-81); WIRN was weighted industry risk for firm i, industry risk was measured at the four-digit SIC code level; SIZE was the logarithm of mean assets of firm i over the 5-year period; NB is the number of

three digit SIC code industries in firm i; RISK is the corporate risk of firm i, defined as the variance of RoA over the 5-year period; RL and UR were two dummy variables, of which RL = 1 was for related-linked firms and RL = 0 otherwise, and UR = 1 was for unrelated forms and UR = 0 otherwise.

Chang and Thomas (1989) did not provide reasons before they proposed an assumed multiple linear relationship between risk, diversification strategies and return. In addition, no reasons were given for using logarithm for measuring SIZE. The correlation coefficients between these variables were not reported to support the construction of the model. A non-significant difference on RETURN among different diversification strategy groups was found based on the results of the analysis of variance of RETURN. However, the two dummy variables representing diversification strategies were still entered into the regression models, even though non-significant results among these strategies were discovered. The regression analysis also showed non-significant effects of these two dummy variables on RETURN. In their research, the two methods were used to estimate the regression coefficients, ordinary least squares method for the two individual models, and generalised least squares for the seemingly unrelated regression model. The estimated coefficients under these two methods were very stable. This increased the reliability of estimated coefficients.

Sa (1988) used three individual multiple linear regression models for three mature industrial products and also combined all variables together into a single multiple linear model using indices and dummies for these three types of industrial products. The models were not reported. Only the results of R^2 for each model were provided.

Multiple linear regression analysis is the most common one used in the manufacturing practice and performance relationship studies in practice because it is easy to be applied. The applications of multiple linear regression analysis in this sub-section do not cover the multiple linear regression models using the stepwise regression procedure, which is presented in following section.

2. Stepwise Multiple Regression Analysis

Fowler and Schmidt (1989) constructed two stepwise multiple-regression models based on the criterion that the incremental r^2 has to be significant at $p<0.01$, provided in section 4.2.3, and the correlation coefficient matrix between each pair of the six independent variables and the two dependent variables in two different models.

In the first model, three of the six independent variables (hostile, age and percentage acquired) reached the criterion $p<0.01$ and entered the model one by one against the dependent variable (change in abnormal returns on common equity-CHGROCE). In the second model, two of the six independent variables (hostile and acquisition experience) met the criterion $p<0.01$ and entered the model one by one against the dependent variable (change in abnormal returns to shareholders-CHGRSH).

In addition, a simultaneous three-variable multiple-regression model with respect to CHGROCE and a simultaneous two-variable multiple-regression model with respect to CHGRSH were also constructed. These two simultaneous models provided the evidence that the variables which were allowed to enter the models explained a big percentage of variances associated with the dependent variables.

Meyer and Ferdows (1990) used stepwise multiple-regression analysis with one and two years time lag to study the relationships between 36 to 39 action programmes from the 1986 and 1987 survey and eight performance indicators in 1988. Both a five-point and a seven-point Likert Scale were used to evaluate the degree of emphasis placed by the respondents on various action programmes in 1986 and 1987 respectively. As far as the 1988 performance indicators were concerned, the respondents were asked to take 1985 as a base year (100) for each of the eight performance measures to indicate how much it changed at the end of 1987. Different number of action programmes (from 0 to 13) of 36 to 39 action programmes which met the criterion were allowed into the models step by step.

Six stepwise multiple-regression models have been constructed in two years time lag (1986 action programmes and 1988 performance indicators). The rest of the two performance indicators in 1988 did not show any relationships with the action programmes in 1986. This was because no single action program met the criterion to construct a stepwise model for these two performance indicators. Seven stepwise multiple-regression models have been constructed within one year's time lag (1987 action programmes and 1988 performance indicators). One of the eight performance indicators in 1988 was not affected by any action programmes in 1987. No correlation between these performance indicators and action programmes were reported. Only the stepwise regression results were given to support their findings.

The two studies presented above developed their multiple linear models using the stepwise regression procedure.

The real situation may be much more complicated than a linear relationship. It may be too simplistic to use linear regression models without the consideration of other alternative models.

3. Multiple Interaction Regression Analysis

The basic interaction regression model including two explanatory (independent) variables interacting with each other has been given in function *4.12* in section 4.2.2.

Chaganti and Damanpour (1991) investigated the relationships between different types of ownership and firm performance. They viewed stockholding by corporate executives as a moderator variable. The moderator variable has been mentioned in section 4.2.2. The outside institutions' stockholding and the moderator were regressed individually and interactively on the performance. The regression model is provided below.

$$Performance = \alpha + \beta_1 moderator + \beta_2 outside\text{-}I + \beta_3 moderator \times outside\text{-}I$$

Performance was measured by one of the following variables, RoA, RoE, P-E ratio and total stock return. The findings did not support the interaction effect of outside institution's stockholding and stockholding by corporate executives on performance. The findings did not support the hypothesis that the interaction of these two types of stockholdings affected performance.

Covin and Slevin (1989) also employed two independent variables, one of which was treated as a moderator, in an interaction model. The difference from Chaganti and Damanpour's interaction model was that Covin and Slevin structured the analysis in several stages. There were three stages in their regression analysis (called moderated regression analysis by the authors). The basic model was a simple linear regression model with one independent variable (organic structure or strategic posture) regressed against performance. At the second stage, the moderator variable (environmental hostility) entered into the basic model to form the multiple linear regression. Stage three involved adding the interaction term between these two independent variables into the second stage's model. The increased power of the regression models supported the hypothesis of the interaction effect of the organic structure or strategic posture and environmental hostility on firm performance. Covin and Slevin's moderated regression analysis is more complete and systematic than Chaganti and Damanpour's model. Covin and Slevin provided a whole situation analysis and the increase or the decrease of power of the models at different stages were observable and the conclusions were convincing.

Arthur (1994) increased the degree of complication of the basic interaction model by including a control variable (Unionization). The control variable has been defined in section 4.2.2, which is an independent variable without interacting with other independent variables in an interaction regression model. Two interacting independent variables (Turnover and HRM related programmes) were added into the model in a two-level's hierarchy. At level one, a linear regression model

included three independent variables without interaction. The interaction between turnover and HRM related programmes entered into the model at the second level. A significant increase of R^2 from level one to level two supported Arthur's hypothesis of the important interaction effect between employee turnover and HRM related programmes on performance, which was measured by labour hours and scrap rate. Cluster analysis has also been used to support the classification of the measurement items of independent variables in this research.

Macduffie (1995) developed a much more complicated interaction regression model by increasing the number of control variables up to five and from two variables interacting to three variables interacting in a two-way and a three-way in a four-level hierarchy. Based on a Cobb-Douglas specification, all the variables were in log transformation. The basic model was:

Log (Performance variables-productivity or quality)
= Log Total Automation + Log Product Design Age + Log Scale
+ Log Model Mix Complexity + Log Parts Complexity

At level two, three practice variables (use of buffer index, work system index and HRM policies index) were added into the basic model without interaction. At level three, three practice variables interacting with each other in two ways (Buffers×Worksystem, Buffers×HRM, or Worksystem×HRM) were added in. Then, the three-way interaction (Buffers×Worksystem×HRM) was added into the level three's model at level four.

Adjusted R^2 was used as a criterion to evaluate the models at different levels. The effects of the interaction among these three variables on the performance were clear during the process of the modelling. In addition, correlation coefficients between dependent and independent variables were reported to support the whole modelling process.

4. Multiple Regression in Log Transformation

Macduffie (1995)'s model, which has been mentioned above, can also be classified into the group of multiple regression in log transformation because it possesses both features of log and interaction. According to figure 4.1 the priority flow chart for classifying multiple regression models, interaction is at a higher priority level than log. Therefore, Macduffie's model has been classified as an interaction regression model rather than a multiple regression in log transformation model in this research.

Silver and Lowe (1989) employed a log transformation of Cobb-Douglas Production function to construct a relationship between labour productivity and capital to labour ratio for individual firms in the Welsh manufacturing industry. The use of a logarithmic scale assumes a Cobb-Douglas Production function with constant returns to scale for each industry investigated in their research. The Cobb-Douglas Production function in their research was given by: $Q = AK^{\alpha}L^{\beta}$, where Q was output, K was capital assets, L was labour employed and A, α and β were parameters where $\alpha + \beta = 1$, α and β are the elasticities of output with respect to capital and labour. The relationship was thus transformed into:

$$Ln \ (Q/L) = LnA \ + \ \alpha \ Ln(K/L)$$

The above regression function can be further transformed into a model in its linearity in parameters. The model included two independent variables in log transformation regressed on a dependent variable in log transformation as well:

$$LnQ = LnA \ + \ \alpha LnK \ + \ \beta LnL$$

The results of the regression model showed the relationship that existed between capital to labour ratios and labour productivity for Welsh manufacturing firms.

Four multiple regression models which were in logarithmic transformation with

various lags of dependent variables regressed on several independent variables, were constructed by Ito and Pucik (1993) to test several relationships.

$$Log\ (EXPORT_t) = \beta_{01} + \beta_{11}\ Log\ (R\&D_{83}) + \beta_{21}\ Log\ (ASSETS_{83})$$
$$+ \beta_{31}\ LEADER + \beta_{41}Log\ (INDR\&D_{83}) + e_1$$

$$Log\ (DOMESTIC_t) = \beta_{02} + \beta_{12}\ Log\ (R\&D_{83}) + \beta_{22}\ Log\ (ASSETS_{83})$$
$$+ \beta_{32}\ LEADER + \beta_{42}Log\ (INDR\&D_{83}) + e_2$$

$$EXPORT\%_t = \beta_{03} + \beta_{13}R\&D\%_{83} + \beta_{23}\ Log\ (ASSETS_{83}) + \beta_{33}\ LEADER$$
$$+ \beta_{43}\ INDR\&D_{83} + e_3$$

$$Log\ (EXPORT_{t\text{-}t\text{-}1}) = \beta_{04} + \beta_{14}\ Log\ (R\&D_{84\text{-}83}) + e_4$$

Where INDR&D was industry average R&D intensity. LEADER was used as a dummy variable to represent the market position of the firm. ASSERT represented the asset size of the firm and R&D represented the expenditure on R&D in the firm. Subscript '83' represented the data at 1983, subscript 't' represented one of the years from 1983 to 1986 in this study, and subscript '84-83' represented the difference in the data between 1984 and 1983.

In Ito and Pucik's study, the four years' data from 1983 to 1986 were collected which made the study on lag relationships possible. The lag relationship is useful for the manufacturing practice and performance relationship studies because it is unlikely for most practices to effect performance at the same year. In this study, the multicollinearity was also tested for each model using condition index and variance inflation factors (VIE). Heteroscedasticity for the sample was also tested using White's test and t-statistics computed from the (asymptotic) heteroscedasticity - consistent variance-covariance matrix. These statistics were not reported in the study. Only the results of ordinary least square regression were reported.

In the study of the relationships between firm growth, size, and age by Evans (1987), maximum likelihood method was used to estimate the parameters of three regression models. Two of these three regression models were in log transformation and one was a probit model. Of the two log transformation models, one involved three independent variables, age, size and the number of plants, regressed against growth and the other model was with the same three independent variables regressed against variability of growth. Second-order logarithmic expansions were used in these three regression models, the growth function, the survival function, and the variability of growth function. A standard probit regression that included a second-order logarithmic expansion was used to represent the survival function. The three functions of growth, survival and variability of growth are listed below respectively:

$$[ln\ S_{t'} - ln\ S_t]\ /d = ln\ g(A_t,\ S_t,\ B_t) + u_t$$

$$E[I\ |\ A_t,\ S_t,\ B_t] = Pr\ [e_t > -\ V(A_t,\ S_t,\ B_t)]$$
$$= F\ [V(A_t,\ S_t,\ B_t)]$$

$$LnStdDev\ (g) = ln\ h(A_t,\ S_t,\ B_t) + w_t$$

Where A, S, B denoted age, size and the number of plants respectively, g was a growth function, I was used in a probit equation to represent a firm survival ($I = 1$) or failure ($I = 0$), $E(I)$ was the conditional expectation of I, V could be thought of as the value (in excess of opportunity cost) of remaining in business, F was the cumulative normal distribution function with unit variance, $StdDev(g)$ was the estimate of the standard deviation of growth, h was a regression function for variability of the growth. V, g and h were approximated by taking a second-order expansion in the logs and their parameters were estimated using maximum likelihood method. u_t, w_t were the disturbance terms (residuals) in normal distribution with mean zero and e_t was a normally distributed disturbance with mean zero and unit variance.

As previously stated, probit equation is used for explaining a binary (0/1) dependent variable. In the survival model, values of dependent variable were either 1 (survival) or 0 (failure). The sum of the probability of obtaining value 0 and the probability of obtaining value 1 was equal to 100%. When data on dependent variables are only available in binary format or only the binary results of dependent variables are interesting to analysts, a probit regression model can be considered.

4.4   Summary

Based on the fundamental knowledge provided, the applications of the models which have been used to quantitatively study manufacturing performance and practice relationships have been presented in two catalogues, correlations and multiple regression models. In the second group, the four types of multiple-regression model applications have been explored. These are summarised below.

1. Correlation Analysis: provides correlation coefficients between each of the two variables, one for practice and one for performance (Calantone et al., 1995; Fowler and Schmidt, 1989; Macduffie, 1995; Bao and Bao, 1989) or a correlation matrix between each pair of variables, no matter performance or practice variables, (Chaganti and Damanpour, 1991; Ito and Pucik, 1993; Richardson et al., 1985; Arthur, 1994; Carpano et al., 1994). Nearly all of these studies (except one) have developed further regression models using correlation analysis results.

2. Multiple Regression Analysis

I. Multiple Linear Regression Analysis

- three independent variables regressed against a dependent variable (Garsombke and Garsombke, 1989; Richardson et al, 1985).
- six independent variables including two dummy variables regressed against a dependent variable (Chang and Thomas, 1989).
- three individual regressions models with five independent variables for

each regression model and the combined regression model pooling all independent variables from the three regression models together using index and dummies (Sa, 1988).

II. Stepwise Regression Analysis

- Two stepwise regression models with six possible independent variables and two dependent variables (Fowler and Schmidt, 1989)
- A series of stepwise regression models with 36 to 39 action programmes as possible independent variables and eight performance indicators as dependent variables in separate models in one and two years time lag (Meyer and Ferdows, 1990).

III. Multiple Interaction Regression Analysis

- two independent variables individually and interactively effecting on the performance variable without a control variable (Chaganti and Damanpour, 1991; Covin and Slevin, 1989).
- two independent variables in the interaction model in a two-level's hierarchy with one control variable (Arthur, 1994).
- three independent variables in two ways and three ways interaction models in a four-level's hierarchy with five control variables in log transformation (Macduffie, 1995).

IV. Multiple Regression in Log Transformation

- Two independent variables regressed against a dependent variable in log transformation (Silver and Lowe, 1989).
- Dependent variables with various lags regressed on several independent variables in log transformation (Ito and Pucik, 1993).
- Three independent variables (age, size and the number of plants) regressed against three dependent variables in three individual models

(two are in log transformation and one is a probit regression model) (Evens, 1987).

The investigation into the types of relationships that may exist between practice factors and performance variables and the methods used in these studies is essential for this research. It forms a foundation for proposing a suitable model or models to explore a certain relationship or relationships hypothesised. Availability of data also constrains a model specification. In the next chapter, research issues and methodological approaches of this research, which cover the possible relationships (gaps in the manufacturing practice and performance studies), sample (data), establishment of hypotheses and approaches used to tackle the hypotheses, will be presented.

Chapter 5   Research Issues and Methodological Approaches

5.1   Introduction

The manufacturing performance and practice and their relationships have been reviewed, the external and internal factors influencing performance have been investigated, and the meta-analysis on the relationships has been conducted in chapter 2 and 3. It is clear that there is insufficient research on this subject, especially quantitative studies on evaluating the strength (effect size) of a relationship. In this chapter, the research issues are addressed in detail. It includes constructing the possible relationships, presenting a UK manufacturing companies' database, and developing and establishing the hypotheses for this research.

The possible relationships are constructed based on the gaps discovered, covering both internal and external factors and their effects on performance. The hypotheses are developed with the consideration of the theoretical work in this area and are established by taking account of both the possible relationships and the availability of the database. Influences of external factors on the relationships are discussed to assist the understanding of the hypothesised relationships. Emphasis is given to the factors related to the establishment of the hypotheses. The methodological approaches, which can be used as a means to develop the models in order to test the hypotheses, are provided afterwards.

Therefore, this chapter consists of the following sections:
1. Constructing the possible relationships
2. Describing the UK manufacturing companies' database
3. Developing the hypotheses on the issues of suitable practice factors and performance variables
4. Establishing the hypotheses for this research
5. Presenting methodological approaches-econometric analysis and multivariate analysis

5.2   Constructing Possible Relationships

As summarised in chapter 3, the results of the meta-analysis provided the six good practices and the three accepted effect sizes of the relationships, which can be a reference to assist manufacturing companies' decision making. These practices are operational management practices and supported by operational management theories, reviewed in chapter 2, section 2.2.3.

Except for these three accepted effect sizes of the relationships, there are many relationships whose effect sizes need to be explored, based on the literature review on the factors influencing firm performance (see figure 2.2 and figure 2.3) and the results of the meta-analysis. Because the gaps on quantitative studies of manufacturing practice and performance relationships are so wide, it is unfeasible to list every relationship that is worth investigating in this area. It is clear that the results of a single study on a certain relationship has less applicability compared with the combined results on the relationship because the situation in which a single study is set only represents certain circumstances. Therefore, the conclusion about the relationship supported by the single study is only valid under those circumstances. However, the conclusions based on the combined results (e.g. meta-analysis) on the relationship have a higher degree of validity because a combined relationship rejects situation specifications proposed in each of the studies included. Therefore the combined results can be applied with more confidence in general cases than those based on a single study.

Gaps

Based on the literature review and the results of the meta-analysis, four types of gaps are considered in this research:

(1) effect sizes of the relationships have been studied in the literature but are unacceptable for general application after combination by the meta-analysis;

(2) relationships between performance and practices which have been proven good by the counting approach but their effect sizes are unknown;

(3) relationships between performance and practices which have been studied and combined by the counting approach with non-significant results and with an insufficient number of the relationships in the literature to draw any significant conclusions; and

(4) relationships between performance and internal practice factors at the firm level or external environmental factors at the industrial or national levels which have not been discovered for studying their effect sizes or not been studied at all, see figure 2.2.

Possible Relationships

Therefore, four groups of possible relationships have been proposed according to the gaps discovered. Factors in the last group can not be listed exhaustedly like the first three groups because it covers much wider context with possible unknown factors, internal or external to firms. The first three groups are directly related to the results of the meta-analysis with clear boundaries.

The first group of the possible relationships between manufacturing performance and practice covers the seven relationships which have been combined in the measuring effect size approach of the meta-analysis with unaccepted effect sizes (see table 3.3). One more single study on these relationships can contribute to combined studies on these relationships in the future. The seven relationships are listed below and ordered by the percentage of observed variance which can be explained by sampling-error, from high to low. These relationships are between:

(1)   age of firm and financial performance;

(2)   implementing action programmes and non-financial performance;

(3)   environmental hostility and 'Return';

(4)   human resource management related programmes and 'labour productivity';

(5)   new product development including R&D and 'Return';

(6)   size of firm and financial performance; and

(7)   focus and 'Return'.

The second group of proposed possible relationships is coming from the counting approach. The six good practices, which have been drawn from this approach of the meta-analysis and supported by the operational management theory, are suggested to manufacturing companies for improving their performance. However, four of these six good practices' effect sizes with any aspect of company performance are still unknown. These four practices' relationships with companies' performance can form the second group for the proposal of the possible relationships. It is meaningful to investigate and discover the effect sizes of the good practices in order to provide a detailed reference for manufacturing companies and industries to improve their performance and establish whether performance improvements outweigh the cost of the practice. These four relationships are between manufacturing performance and the following practice factors:

(8)   quality management programmes;

(9)   flexible manufacturing system;

(10) long-term investment; and

(11) lean production.

The third group for proposing possible relationships is based on the inconclusive research to date. According to table 3.2, there are six relationships between practices and performance with non-significant differences between the numbers of positive and negative signs reported in the literature and four relationships with insufficient numbers reported to draw conclusions. Even for the six relationships with non-significant differences between the number of positive and negative signs, the number of signs related to a relationship reported is less than 10 cases except for two of them with 17 reported. Therefore, more research is required in order to draw more rigorous conclusions on these relationships.

Among these six relationships with non-significant differences between the number of positive and negative signs, the relationship between diversification and performance has been combined quantitatively and its non-significant effect

size on performance is accepted. Relationship between 'firm age' and performance, relationship between 'firm size' and performance and relationship between 'focus' and performance have already been catalogued as the part of possible relationships in the first group. Considering the four relationships with insufficient numbers reported, the following six relationships are listed in this group. They are the relationships between performance and the following practice factors:

(12) use of technology;

(13) unionisation;

(14) strategic planning;

(15) cost reduction;

(16) export; and

(17) market share.

The last group covers the relationships between the factors, which have not been discovered in empirical studies however are supported in the operational management or the economic theories, and firm performance. These factors are listed in two sub-groups separating internal and external factors. It is impossible to exhaustively include every single factor which may be relevant to firm performance. The factors listed below are only based on the difference between theoretical studies and empirical studies in this area.

There are five internal practice factors that are worth further investigating (see table 2.2):

(18) capacity management;

(19) inventory management;

(20) supply-chain management;

(21) MRPI and MRP II; and

(22) BPR.

These practices are supported by the operational theory as good practices but their effect sizes on firm performance are not confirmed or studied by empirical research to reach conclusions.

The following external factors, which have been summarised at the section 2.2.2, can be influences of firm performance and are worthwhile to be investigated:

(23) industrial characteristics and structure;

(24) industry life cycles and business cycles;

(25) technology changes and opportunities at the industrial level;

(26) market structure;

(27) economics of scale;

(28) government policies;

(29) manufacturing investment incentives;

(30) exchange rates;

(31) interest rates;

(32) oil prices;

(33) total investment;

(34) economic or environmental stability;

(35) inflation; and

(36) growth or recession.

Only a few external factors listed above have been studied related to their effect sizes on firm performance in empirical work, such as environment variables, environment hostility and organisation structure (also see, table A.1 in appendix 1). But the studies on these factors have not generated general conclusions on whether they are beneficial to firm performance. Therefore, these factors can be included in the possible relationships for further study as well. They may not act as factors directly affecting firm performance but they may perform as moderating roles to firm performance.

Performance measures for these relationships need to be specified if they are

chosen as the hypotheses for this research after considering availability of the UK companies' database in the next section.

In summary, 36 relationships between practice and performance in manufacturing industry have been proposed as valuable possible relationships for further study. It does not mean that other relationships excluded are not important. It is only because the listed possible relationships would make a more valuable contribution to the current research situation in this area, according to the literature review and the results of the meta-analysis.

5.3   Sample

The researchers had maintained a company database that includes four tightly specified manufacturing sectors of UK industry: special machinery (for example, manufactures of printing, food equipment, textile machines), fluid handling equipment (for example, manufactures of pumps, valves and compressors), electronic engineering and clothing (Groves, 1988, Hodges & Hamblin, 1989, Hamblin, 1989 and Groves & Hamblin, 1990). It initially had a total number of 175 companies from 1979 to 1988. This initial database has been extended within this study from 1989 to 1995 with a size of 96 companies in the most of the variables except for the variable of the use of technology, which has only 45 companies' responses of the questionnaires.

This original database was collected under EPSRC and DTI project grants (6 person-years) by interviewing and observation within the companies and therefore the reliability is high. For example, non-manufacturing activities could be excluded, and the performance reflects that of manufacturing activities alone. This original set of the database was gathered by researchers in Cranfield University and transferred with the grant holder to the University of Luton. The extended set of the database was collected mostly through FAME on CD Rom and from the Companies House information within this PhD research programme. The quality of the information should be ensured by these two sources, although the reliability must be lower than data captured in companies. Some variables, particularly in practices, need further data from the companies, but revisiting each was

infeasible. One variable in the extended set of the database is technology usage, which was collected in this study through the questionnaires due to the information on the use of technology not being available from the FAME and the Companies House. The methods used to collect the variables for the second part of the database were constrained by the financial and time resources of this project.

In the initial set of the database, there are two parts. One covers the variables in numerical format and the other part is on the factors that could not be measured in numerical format, which provided detailed information on the companies with open-ended questions (appendix 2). In the part with open-ended questions, company's age, the information on quality and new products development are provided. The information on quality and new product development has to be converted to be used to study the sizes of the relationships between these factors and manufacturing performance. Due to the characteristic of this research, which is quantitatively studying the sizes of the relationships, the data that is in numerical format is mainly considered to construct and test the hypotheses. For each company, the numerical raw data have been collected as follows from 1979 to 1988 and listed in appendix 3.

The following variables have been calculated using raw data listed in appendix 3:
- Value added =Turnover - Material and subcontract costs
- RoS = Return/Sales = Profit before tax/Turnover
- RoA = Return/Asset = Profit before tax/non-land and building fixed assets
- Capital efficiency = Value added/Capital cost (depreciation, rents and leases)
- Employment efficiency = Value added/Employment cost
- Labour efficiency = Value added/Employees
- TFP = Value added/Total of capital and employment cost
- Total Investment % = Total spend/Value added
- Investment-LBsp % = (Total spend –Land and building spend)/Value added.

A company's size can be measured by either the number of employees or the

value added or capital employed in this database. The reason to normalise the investment by value added to calculate the investment percentage is because the influence of the company's scale of activity on investment can be taken into account.

The variable of technology usage is a specific case. Strictly speaking, in this research context, the use of technology means the use of advanced manufacturing technologies (AMT). In most of the previous studies reviewed, the technology usage was measured by the number of technologies used in a company. However, it will be a more accurate measure if more factors related to technology usage, such as utilisation of the technologies, but not just counting the number of them, can be taken into account as well. This is because the technology usage level can be different for two companies employing the same number of the technologies. For example, two companies may employ the same technology, but they may differ in the degree they actually utilise this technology.

The list of the technologies included in the original database is given in appendix 4. In this research, technology usage reflects not only the number of technologies, which have been used in a manufacturing company, but also on their excellence. This measurement system on technology usage was developed by the researchers collecting the original database. The excellence of a technology usage includes as many as are available of the following dimensions: the utilisation of the technology, the percentage of the activities produced by the AMT, and the degree of satisfaction of the activities done by AMT. Measurement of the technology usage that takes into account the extent of the use rather than merely its existence has not been discovered in other studies. In the initial set of the database, the four manufacturing sectors have employed slightly different measurement systems for calculating the indices of technology usage. Different measurement sets had been used in the earlier studies. This was due to the different opportunities in the separate sectors, and to continuous improvement of the research process. In order to derive a common technology usage index, the available data have been manipulated to a common base. The formulae were devised by the original

research team and the resulting ranking of companies was verified by the team.
A common system has been used for the extended set.

For the initial part of the database, the technology index is obtained by the
consideration of the items that have been listed in table 5.1 for each sector.

	Clothing		Special Machinery		Fluid Equipment		Electronics	
	items	*scale*	*items*	*scale*	*items*	*scale*	*items*	*scale*
I_1	cad83	1-2	shifts	1-3	shifts	1-3	amt design	1-3
I_2	cad87	1-2	utilisation	1-100	utilisation	1-100	amt assemy.	1-3
I_3	comp83	1-4	act/amt	1-100	act/amt	1-100	amt test	1-3
I_4	comp87	1-5	No of amt	0-9			amt mgt. ctl.	1-3
I_5	amt83	1-3						
I_6	amt87	1-3						
RI	$4*[\Sigma(I_1,I_6)]-6$		$I_3+(I_1*I_2)/3+10*I_4$		$(I_1*I_2)/3+I_3$		$[\Sigma(I_1,I_4)-4]*12$	
I	RI		RI/Max(RI)		RI/Max(RI)		RI	

Cad83(87):   Computer aided design in use in 1983 (1987)
Comp: Computers for administration and control
Amt: Advanced manufacturing technology in production
Act/amt: Activities produced by AMT
RI: Raw technology index
I: Final technology index

Table 5. 1   The Items Included in Technology Index and the Calculation

Formulae of Technology Index (I) for Each Manufacturing

Sector

Table 5.1 provides the details of the items that have been included in the
technology index in each sector. The formulae used to calculate the raw
technology index (RI) and the formulae to convert RI to I, if RI in that sector is
not in the 1 to 100 scale, are also given.

The technology index for the second part of the database comes from the average
of all the aspects that are related to technology usage excellence. As mentioned
before, they are the percentage of the activities that have been produced by AMT;
the degree of the satisfaction of these activities done by AMT and the utilisation
of AMT, measured by percentages. The first two aspects involve the three parts,
design, production and management controls. The utilisation, including the shifts
of AMT and average percentage of the shifts utilised by AMT, is only relevant to

production part. Even though the same formula is used to calculate the technology index, the technologies that have been employed in each manufacturing sector are different from each other due to the characteristics of each sector. The questionnaires on technology usage of the four sectors for the extended database are provided in appendix 5.

The hypotheses are constructed with the consideration of availability of the original part of the database. The second part of database is extended afterwards. Therefore, the relevant variables, required to test the hypotheses for this extended period from 1989 to 1996, have been collected. The details of the variables collected are given in the next section. The extended database is less detailed than the original database, being limited to the data on the variables used to test the hypotheses. The reports using the original database for each sectors have been published in the past (Groves, 1988, Hodges and Hamblin, 1989, Hamblin, 1989 and Groves and Hamblin, 1990) to provide descriptive information of the variables. The descriptive information of the extended data is provided in the next section using the extended sample as a whole.

5.4   The Descriptive Information of the Extended Database in the Early 1990s

The extended database includes 96 companies that still manufactured in 1996, of which 45 replied to the questionnaires on technology usage. There are still four sectors in the extended database. The figure 5.1 shows the percentage of each sector of the total sample size in the extended database.

Sector Size

Machinery 24%
Clothing 11%
Electronics 38%
Fluid Handling 27%
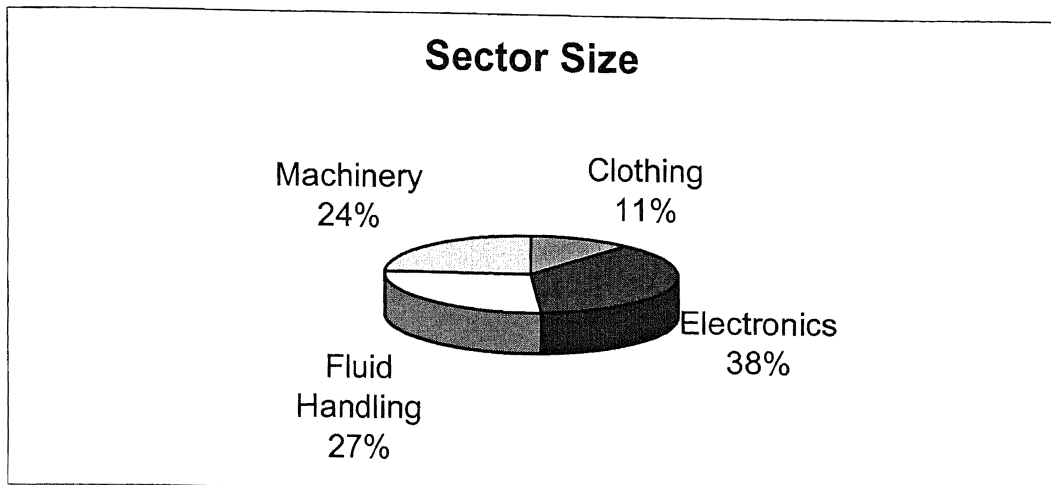
Figure 5. 1   The Percentages of the Sectors of the Total Sample in the Early 1990s

The variables included in the extended database include the following: turnover, profit before tax, return on capital employed (RoA), depreciation, remuneration (cost of employment), investment, number of employees and capital cost. Value added, TFP and RoS are calculated from these variables.

Because the details of data on materials and subcontracts' cost were not available in the extended database, a ratio of value added to turnover for each sector is calculated based on the original database. Value added for each individual company in each year of the extended period is then calculated based on its turnover and the ratio of the sector. The assumption is made that the ratio of materials to turnover is stable over time. This assumption is certainly valid throughout the 1980s period where less than 0.2% *pa* movement was detected in the sector ratio, and therefore the extrapolation has face-validity. Clearly there will be some errors if structural change within a company, or a sector, has radically altered the ration of materials to turnover. This would affect the accuracy of the TFP performance estimate. TFP is obtained using value added divided by the cost of employment and capital. RoS is calculated using profit before tax divided by total turnover.

The average of each variable collected for the companies has been calculated for each year. The averaged value of each variable has been used to generate the charts to describe the variables and their changes during this period. For the variable that is not in a percentage ratio, a column chart is used to show the actual amounts. Otherwise, a line chart is used. Not all variables collected in the extended database are used to generate charts. The relevant ones have been used.

Firstly, the investment amount and investment percentage of value added during this period are given in figure 5.2 and 5.3.
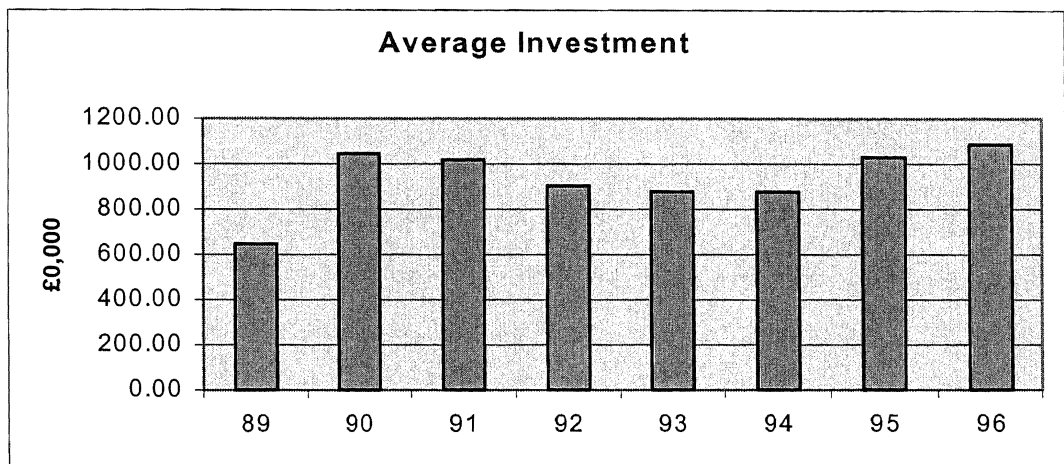
Figure 5. 2   The Investment Amount from 1989 to 1996

Figure 5.2 shows that the changes of the investment amount during this period were not dramatic, except for a relatively large increase from 1989 to 1990. A slight but steady decrease started from 1991 to 1993 and 1994 during the UK economic recession period. Afterwards, the recovery in investment amount occurred in 1995 and then in 1996. However, whether the changes in investment amount are consistent with the changes in the scale of throughput, which is value added in our case, is discovered in figure 5.3.

Average Investment % of Value added
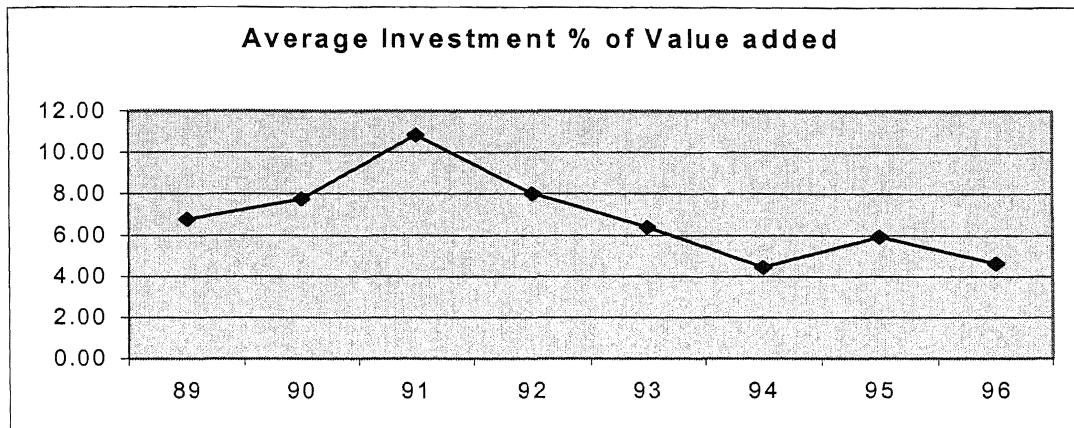
Figure 5. 3   Investment % of Value Added from 1989 to 1996

Figure 5.3 indicates changes of investment as a percentage of value added from 1989 to 1996. The peak of investment percentage of value added in 1991 is due to low value of value added in that year rather than a real increase in investment amount. In general, it was not the case that the investment amount followed value added. Actually, the investment percentage of value added has decreased over this period since 1991, except for year 1995. This means that investment was weak during this period, and confirms the work of Kitson and Michie (1996) that the decline in the UK economy was due to under-investment.

The changes of the three performance variables which have been considered in this research as performance variables, which are RoS, RoA and TFP, are given in figures from 5.4 to 5.6.
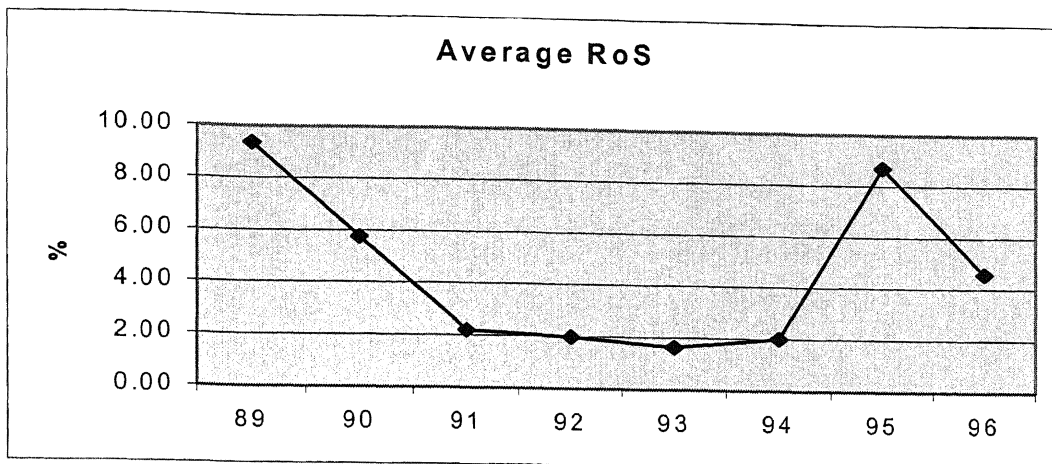
Figure 5. 4   RoS from 1989 to 1996

Figure 5.4 provides the pattern of RoS during this seven years' period. There were dramatic decreases from 1989 to 1991, due to dropping of profitability alone with slight increasing of sales of these companies during these years. In 1992, even though the average of RoS of these companies is above zero, there were quite a few negative figures in individual companies. RoS dramatically dropped from 1989 to about 2% where it had persisted for about 4 years until recovery in 1995 when it again went back to slightly above 4 %. The change of RoS during this period is consistent with the economic recession in this country.
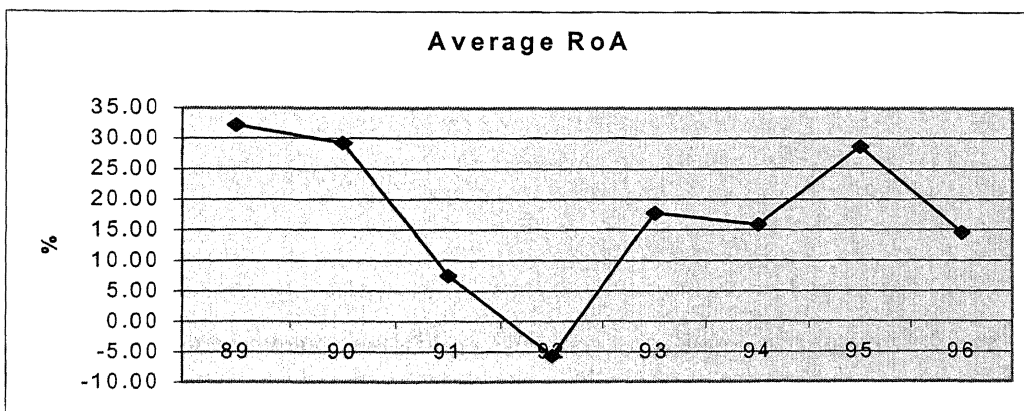
Figure 5. 5   RoA from 1989 to 1996

The data of RoA have been directly collected from the financial information provided in FAME. In 1992, there were large losses in profit before tax in some companies, which generated the negative figures of RoA in these companies and results in the negative average RoA in 1992. This is consistent with the UK economic recession of the early 1990s, especially in 1992. After 1992, the economy was slightly recovering and RoA reached its peak in 1995 after the recession and decreased in 1996 back to the average of this period, about 15%.
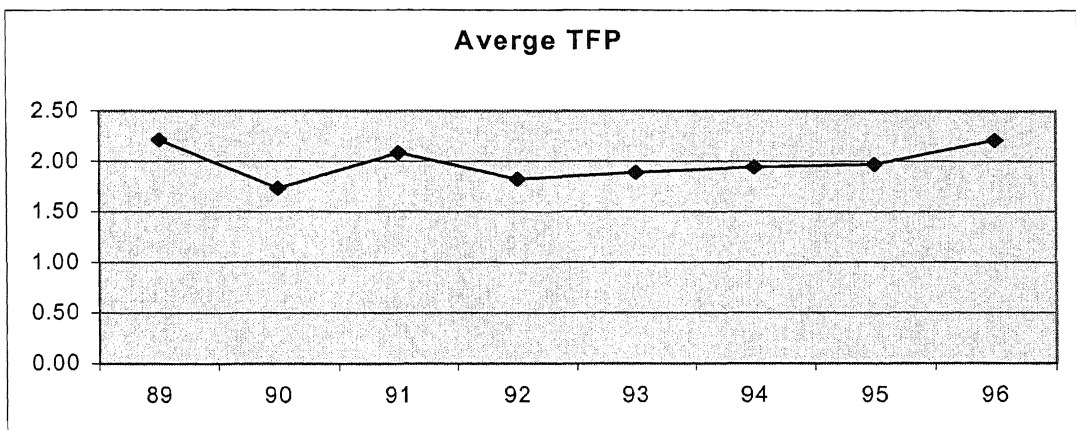
Figure 5. 6   TFP from 1989 to 1996

TFP has been calculated to represent the companies' overall efficiency for this period. TFP is a significant measure of company performance for both labour and capital intensive industries and is the most effective way of combining the constituent labour and capital efficiencies (Hamblin, 1989). TFP was very stable during this period with a slightly upward trend through the period from 1992 to 1996. Average TFP was about 2.

Also, the descriptive information on three other variables, which are relevant to calculate the performance variables in this research, is given in figures 5.7 to 5.9.
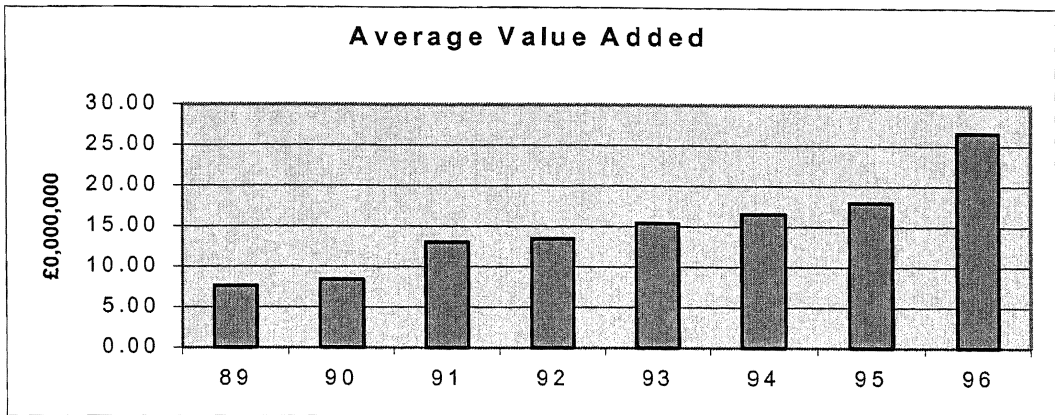
Figure 5. 7 Value added from 1989 to 1996

Figure 5.7 indicates the change of value added in this period. A steady increase of the average value added persisted during this period to reach a peak in 1996. It may be due to efficient use of material and reduction in subcontract costs or a recovery of the net value of economy.
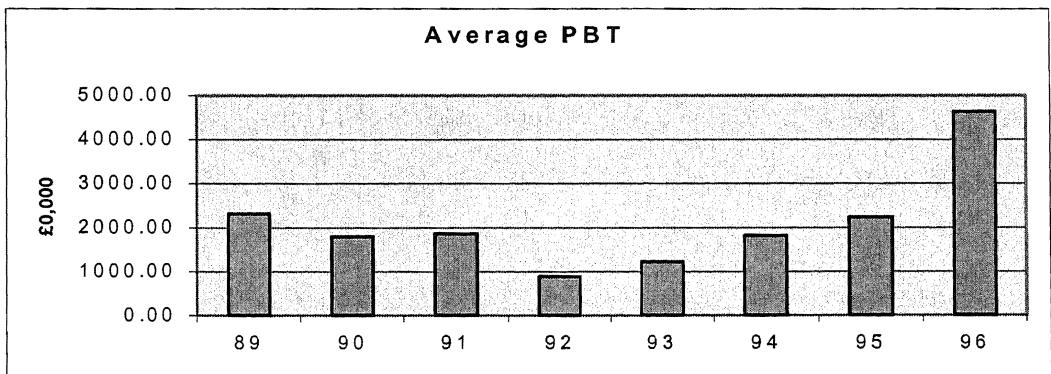
Figure 5. 8 Profit before Tax from 1989 to 1996

Figure 5.8 shows the changes in average profit before tax. Generally speaking, there is a decreasing trend in PBT from 1989 to 1992 and an increasing trend from 1993 afterwards, reaching its peak in 1996. The changes on this profitability measure are also consistent with the recession in the early 1990s.
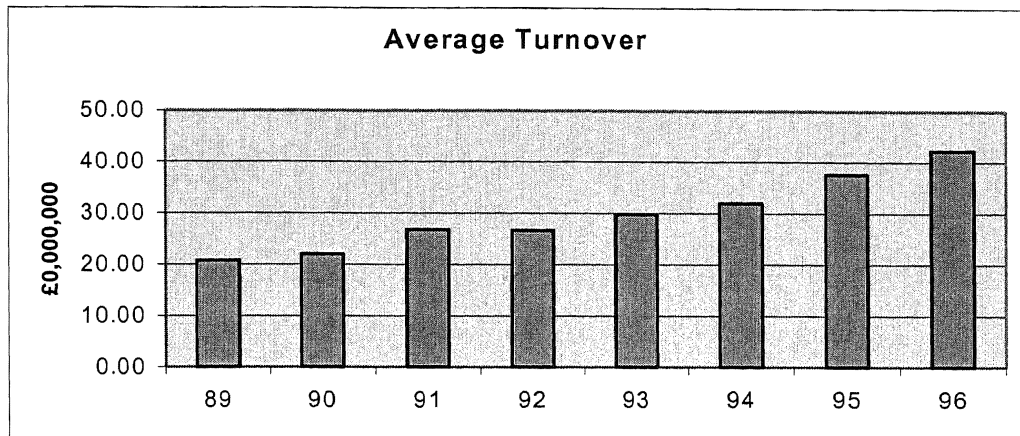
Figure 5. 9   Turnover from 1989 to 1996

Figure 5.9 provides the changes in turnover. The values of turnover used in above have been modified by taking off 10 % inflation, according to Healey (1993). It may be surprising that the consistent increase of turnover through this period and value added as well. These two steadily increased absolute variables and other variables measuring profitability, such as PBT, RoS, indicate that an increase in these absolute values may not bring an growth of net profit at the end.

5.5   Developing and Establishing Hypotheses for this Research

In this section, hypotheses for this research are developed and established. The process of development of the hypotheses involves three steps. At the first step, suitable practice factors are selected based on the possible relationships, the availability of the database, and the consideration of the theories of the operational management. Also, performance variables are chosen based on the availability of the database and the conceptual performance system. At the second step, the review of the empirical work on the relationships between the factors selected and their effects on manufacturing performance is conducted, with the consideration of the influences of the external factors, reviewed in section 2.2.2, on the relationships. At the last step, the hypotheses for this research are established.

5.5.1   Development of Hypotheses on the Issue of the Selection of Suitable Practice Factors and Performance Variables

With the consideration of both of the possible relationships listed in section 5.2 and the availability of variables in the database described in section 5.3, the following factors can be explored. They are, age of firm, size of firm, investment, technology, new product development (NPD), and quality management. These factors fall into the first three gaps, which are related to the operational management domain. The external or economical factors summarised in the last group possible relationships can not be considered for the establishment of hypotheses in this research because the database lacks relevant data and the focus of this research is set on manufacturing practices at the firm level. However, the moderating functions of these external factors can not be neglected to explain the relationships between manufacturing practices and firm performance, even though the external factors can not be directly studied and built into models in this research.

Of the practices listed above in the operational management domain, attention has been paid to technology usage, quality management, new product development, and their positive effects on manufacturing performance in the operational management theory. In the theory, these factors are good for manufacturing performance. However, there is still confusion on these practices and their effects (and effect sizes) on manufacturing companies' performance improvement in the published empirical studies employing real life cases or data. In order to be able to consider possible new types of econometric models, the ratio data variables are pursued in this study. However, the database on quality management and NPD are limited to the ordinal data only. Therefore, the use of technology has been selected as one of the practice factors for establishing the hypotheses.

Besides, investment in design has been mentioned in the operational management theory. Investment analysis can be an independent topic investigating investment at the different levels, such as state investment, industrial or sector investment, and company investment. Also, investment appraisal and decision methods can be

included in investment analysis. In this study, the focus is set in the behaviours of manufacturing companies. Therefore, investment in companies should be considered for investigation. Investment in companies is not only on design and implementation of new or improved products, services and process suggested by the operational management theory, but also on the maintenance and improvement of management planning and control and more. The effects of investment on performance have been a slight neglected topic in recent years' empirical studies. The function of investment needs to be re-estimated, especially at the micro economic level, in which more confusion has occurred, according to the results of the meta-analysis. It has been a universally accepted theory that a company cannot maintain or grow without investment. In addition, the forms of investment, such as long-term and short-term, may cause different effects on firm performance. Investigation of these aspects of investment can be useful. Therefore, investment has been selected as a factor in this research for constructing the hypotheses, with consideration of its different forms.

Furthermore, investment and technology usage can be two closely related factors in operational practice. This is because new technologies are frequently, but not universally purchased or implemented with investment being involved. The reasons behind these two factors and their association are discussed in detail in the next section. Hence, the relationships between investment and the use of technology and manufacturing performance are developed as focuses for the hypotheses to be established in this research and explored in great detail.

For performance variables, the variables such as RoS, RoA and efficiency variables (TFP, labour efficiency, and employment efficiency) are available in the database and can be used in the models to test the hypotheses. Therefore, the performance variables are limited to financial and efficiency ratio measures in this research. Non-financial performance can not be considered. In order to establish the hypotheses, an investigation into the relationships between investment, the use of technology and performance is necessary.

5.5.2   The Relationships between Investment, the Use of Technology and Manufacturing Performance

Although manufacturing investment is a mature research topic, most discussions have been on the appraisal of investment projects as high-risk, long-term, future investments. There has been less literature on its actual historical effect on companies' performance.

There are a few studies on the relationships between manufacturing performance and long-term investment or investment related factors (Covin & Slevin, 1989; Buckley et. al., 1990; Oulton, 1989; Schmemmer & Rho, 1989, Hamblin, 1990 and O'Mahony, 1994,). One of these studies (Covin & Slevin, 1989) reported a positive correlation coefficient (0.22) between long-term capital investment policy in a hostile environment and performance, which was measured by a financial performance index. The correlation coefficient was significant at 5 percent level and therefore it has been accepted. In Buckley et al.'s study (1990), a positive relationship between foreign direct investment and companies' performance, which was measured by profit and market share, was concluded by investigating several cases. Oulton (1989) studied the relationship between the investment in new and scrapping of old equipment and productivity growth in UK manufacturing industries from the 1960s to the 1980s. He found that there was an effect of both actions on productivity growth rates in the 1960s and the 1970s, but not in the 1980s. Based on the results of the several regression models, Schmenner and Rho (1989) concluded that investment in new technology increases factory productivity. O'Mahony (1994) concluded that the productivity gap between UK and four other major industrial nations could be reduced by raising the level of investment in physical capital, research and development and workforce skills. However, one part of the earning-investment causality results, mentioned by Hamblin (1990), was that "making a high level of investment has not led to incremental profit performance."

Investment in these studies was set either at company level or national level. Two studies using foreign direct investment and national investment in physical capital

were considered at the national investment level. The rest of the studies were set in companies. Although most of these studies suggested that there were positive effects of long-term investment (no matter what type of long-term investment employed) on performance, the sizes of the effects in general were not researched in most of these studies. The studies investigating companies' investment employed a segment of investment (e.g. investment in equipment) as the investment variable or an investment related factor (e.g. investment policy) rather than studied the investment as a whole, which occurred in a company during a year, except for the study by Hamblin (1990). The studies on the certain types of investment contribute to the knowledge at the certain aspects of investment.

Investment in manufacturing is mostly for the long term. Long-term investment is unlikely to fulfil its entire benefits in the same year and it is impossible to secure all its benefits in such a short time. It is more likely to cause opposite effects (negative) on the same year's financial performance if no other factor is considered and a single year's investment is researched. This is because an investment invested in a year increases the costs of the company in that year and is unlikely to contribute to the performance within that year, even though the investment may contribute to performance later on. However, no single study, which has been discovered in the literature until 1996, researched the delay effect of investment on manufacturing performance. One study (Hamblin & Lettman, 1996) identified a delay effect of investment on manufacturing performance based on the UK clothing industry, among other effects.

Furthermore, investment in a manufacturing company in a single project can be implemented over many years. Therefore it is meaningful to study cumulative investment as well, which has not been researched in the studies discovered in this area. Delay effects of investment and cumulative investment are supported by investment project appraisal methods. In investment project appraisal methods, the benefits brought from an investment project are always assumed to be spread over several years to fully reflect the benefit of the investment (Oldcorn and Parker, 1996). Therefore, investment in a single year with and without time lag

and in cumulative format is considered and investigated in this research.

Investment in long-term capital could increase the possibility of the use of advanced technologies in companies or industries if part of the investment were on advanced technology and therefore might affect performance. Several articles have studied the relationships between the use of technologies and manufacturing performance (Garsombke & Garsombke, 1989; Sa, 1988; Roth & Miller, 1992 and Carr, 1988). However, they provided different findings, some of them positive and some of them negative (Li & Hamblin, 1996).

Garsombke and Garsombke (1989) studied the effect of the three types of technology: robotization, computerization and automation on performance. Their regression results suggested that "computerization and robotization contribute to the most positive change of performance, however, the automation variable does not appear to conform to performance enhancement theory". Carr (1988) stated that high technology is not always essential to success. Advanced manufacturing technology and technical sophistication of equipment are key success factors for manufacturing companies (Sa, 1988 and Roth & Miller, 1992). In the theory, employing advanced or new technology is always assumed a success factor in the long run, even though it is unclear in practice whether the use of technology always contributes towards the company's performance or not in general. Investment could be related to different level's technology usage in a company. The net benefits of implementing a technology depend on the cost and other uncontrollable or external factors (such as environment or government policy changes). The use of technology and long-term investment could be two factors bounded together to influence manufacturing companies' performance. The use of technology can also be viewed as a moderator to the relationship between investment and performance. This will allow the differentiation between, say, heavy investors in new technology, light investors in new technology, heavy investors in conventional technology and those companies who invest hardly at all. Figure 5.10 represents the interaction association between investment and technology usage.
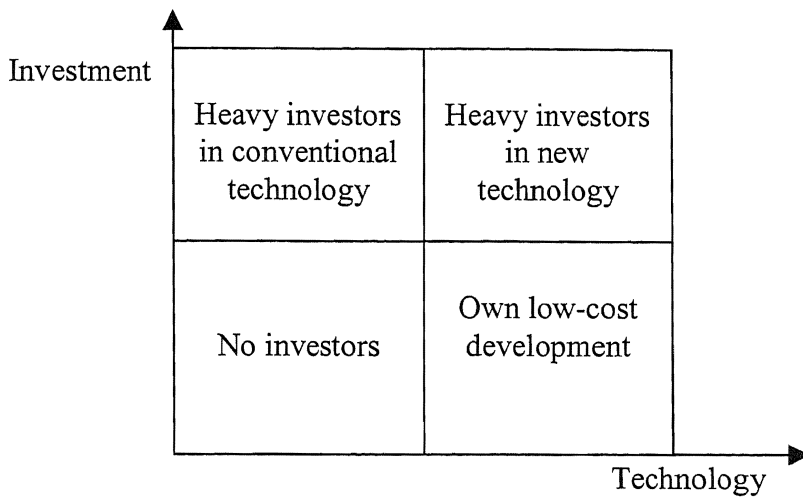
Figure 5. 10 The Combination Results of Different Levels' Investment and Technology Usage

It is important to recognise the influence of external factors on the relationships between investment, technology usage and manufacturing performance. This is because that these external factors form the environment for the companies and affect decisions of companies on investment and technology usage. They also affects the manufacturing companies' performance.

Three groups of external factors have been identified in section 2.2 and generate the last collection of the possible relationships for further studies. The first group includes the factors at the industrial level or measuring industry status. They have more direct influences on firms compared to the factors in the other two groups. Industrial characteristics and structure is an essential factor which is directly related to the amount of investment and the required degree of technology in an industry or a sector. Investment and related factors such as investment decisions and policies and the necessity of investment in technologies can be different between technology intensive industry and labour intensive industries or sectors. For example, a technology intensive industry may need more investment in expensive equipment and technology. In the database used, there are four industry sectors, the amount of investment and the level of the expense and usage of

technologies are different between, say, the clothing sector and the electronic sector. Also, in this group, the factor of the opportunities at the industrial level is essential to the investment decisions and opportunity of technology usage in manufacturing companies.

In the second and third groups of external factors summarised, the factors such as investment incentives and total investment in the nation and government policies related to investment intention and directions can also impact on manufacturing companies' investment decision and the performance out-turn. Oil prices and interest rates are two important factors to the national economic stability. Interest rates influence the exchange rates and may affect manufacturing companies' trading and their performance. This point has been made and supported in the UK economic experience. Economic stability and growth provide the opportunities and ability for the nation, industry and companies' investment. In the two recession periods, manufacturing companies could not afford decent amount investment.

It is important to recognise these external factors discussed and their effects on investment decisions and the opportunities of technology usage in manufacturing companies. However, it is essential to realise these factors impacting manufacturing performance mostly through investment and technology usage. The relationships between these external factors and investment or technology usage are not set as the study objectives in this research. The scope of the database also constrains the exploration of these factors by modelling, as has been discussed in section 5.5.1. The modelling is on the relationships between investment and technology usage and firm performance. The external factors are used to further explain the results of the modelling and gain a wider and deeper understanding of the relationships studied.

It has been noted that there is no single study that studied more than one performance variable in a single model. It may be due to the difficulty and constraints of building and estimating a model with more than one dependent

variable. However, it is possible to develop a model with more than one dependent variable and a method to estimate the coefficients of the model. This is particularly meaningful for a factor such as investment which may affect two dimensions of performance. Investment may be made to increase the capacity of an organisation (growth), or to increase the effectiveness of an organisation (profitability). This is because that investment could contribute to profitability and growth at the same time or that investment may not contribute to profitability but contribute to growth of a company or otherwise. In this study, the hypotheses are also constructed with the consideration of the two dimensions of performance. The measure for growth is value added growth. The theory of building a more than two dependent variables' model is multivariate analysis.

In this research, the investment variable is the non-land & building capital investment divided by the value added (Hamblin and Lettman, 1996). The reason for excluding investment in land and building is because a major amount of investment in land and building in a certain year distorts the main pattern of investment. The use of percentage investment by the value added is to eliminate the influence caused by the differences of company sizes. The measure of the use of technology is mentioned in section 5.3, which is a composite technology index on both the numbers of technologies employed and the factors related to their excellence in use.

5.5.3   The Hypotheses for this Research

Based on the review and analysis of the factors of investment and the use of technology and their possible effect on manufacturing performance, the following three relationships between them are possible.

Investment   ⟶   Performance

Use of Technology ⟶   Performance
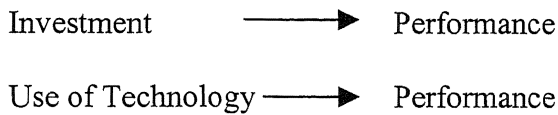
Figure 5.11a   Investment or the Use of Technology alone affects performance

Use of Technology

Investment   ⟶   Performance
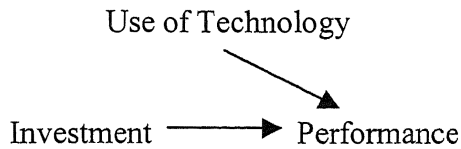
Figure 5.11b   Investment and the Use of technology together without interaction affecting performance

Use of technology   Investment

                        Or/and

Investment ⟶ Performance   Use of technology⟶ Performance
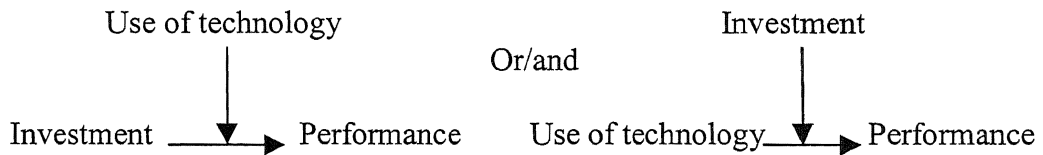
Figure 5.11c   Interaction effect of investment and the use of technology on performance

Figure 5. 11 Possible Relationships between Investment, the Use of Technology and Performance

Figure 5.11 shows the three possible relationships between investment, the use of technology and company performance. Figure 5.11a represents a direct causal relationship with one independent variable, which is a kind of relationship in which a variable (investment *or* the use of technology) is a direct cause of another variable (manufacturing performance). Figure 5.11b depicts a direct cause relationship with two independent variables, which is a kind of relationship in which two variables (investment *and* the use of technology) are two direct causes of another variable (manufacturing performance). Figure 5.11c represents a moderated causal relationship, in which the relationship between two variables (investment and manufacturing performance, or use of technology and manufacturing performance) is moderated by the third variable (the use of technology, or investment). If there is no priority of these two independent variables to the performance variable, the possible relationship between them

should be treated equally. Then we can call the relationship an interaction casual relationship. The details are discussed in chapter 6 regarding the model development. In the relationship illustrated by figure 5.11c, a multiplicative interaction between investment and technology usage is one of the causes for performance improvement. In order to discover which relationship described above represents the best association between these factors or variables, these three possible types of relationships have to be considered together.

In the studies related to construction and test of hypotheses in management science, an alternate hypothesis (there is something there, a positive or negative relationship) rather a null hypothesis (there is nothing there, no relationship) is used to state the possible relationships supported by the literature review (Neuman, 1999). He mentioned that "a hypothesis can be stated in several ways" and also give an example using ten different ways to address a hypothesis (page: 129). It is different from the pure mode used in statistics. In management related topics, statistics is a tool or only a tool to assist the discovery whether there is a relationship or not. Therefore, the possible direction (positive or negative) of a relationship (an alternate hypothesis using statistic language), which are implied through the literature review, is used for the statement of each hypothesis.

The hypotheses related to the effects of investment, technology usage, and their multiplicative interaction between them on a single performance variable are constructed below. These hypotheses are called stage 1 hypotheses.

(H1) Investment in a single year has a negative effect on manufacturing companies' performance in that year but has a delayed positive effect on it in later years.

(H2) Cumulative investment has a positive effect on manufacturing companies' performance.

(H3) The use of technology has a positive effect on manufacturing companies'
performance

(H4) The multiplicative interaction between investment in a single year and the
use of technology has positive effect on manufacturing companies'
performance.

(H5) The multiplicative interaction between cumulative investment and the use of
technology has positive effect on manufacturing companies' performance.

The three formats of investment (a single year's investment without time delay, a single year's investment with time delay and cumulative investment) are tested in the hypotheses at stage 1. The best form of investment (the form which has the greatest positive effect), which is uncovered at stage 1, is used to build the models involving two performance variables. The hypotheses related to two dimensional performance measures are called stage 2 hypotheses. The investment variable mentioned in these hypotheses can not be specified at this stage.

(H6) Investment in a certain form has positive effect on manufacturing
performance not only in profitability but also in growth.

(H7) The use of technology acting as a joint factor with investment in a certain
form has positive effect on manufacturing performance in both of the
dimensions, profitability and growth.

5.6   Methodological Approaches-Econometric Analysis and Multivariate Analysis

In order to test the two stages' hypotheses, the methodological approaches have to be determined before the developments of the models.

The characteristic of this research is to explore the relationships quantitatively. The focus is on the relationships' general application with discovering the sizes of the relationships rather than exploring qualitatively the details of a situation of the

relationships in companies.

The methods used to test the sizes of the relationships are available from econometric analysis for the models with a single performance variable and multivariate analysis for the models with two or more performance variables. The details of the models and the estimation methods have to be developed. The development of the models that are used to test the hypotheses is presented in the next chapter.

5.7   Summary

In this chapter, the research issues, which cover the construction of the possible relationships, the sample, the development and the establishment of hypotheses, and the methodological approaches, are addressed. The possible relationships are proposed based on the gaps discovered in the literature review and the meta-analysis. The database including the original data set from 1979 to 1988 and the extended data set from 1989 to 1995 are described and verified as far as is practicable. Investment and the use of technology have been selected as practice factors used in the hypothesised relationships by considering the database, the possible relationships and the theory in this area. The hypotheses on the relationships between these two practice factors along with their multiplicative term and a single performance measure and two dimensional performance measures are established at the two stages. The establishment of the hypotheses is also based on the review of the literature of the relationships between investment and performance and the relationships between the use of technology and performance.

The influences of the external factors, such as industrial characteristics, the national or industrial investment policies and incentives and total investment in manufacturing sectors, economical stability, and even interest rates and oil prices, on the relationships between investment and the use of technology in companies and firm performance, have been discussed briefly. The further analyses on the results of the modelling with the consideration of these external factors are given in chapter 8.

Finally, the brief introduction of two methodological approaches-econometric analysis and multivariate analysis has been given for being used to tackle the constructed hypotheses. The details of the development of these methods are presented in the next chapter.

Chapter 6   Developing Suitable Methods

6.1   Introduction

In this chapter, the methods that are used to test the hypotheses are developed and presented in two stages. Stage 1 involves the models developed for a single performance variable. Stage 2 deals with the model with two performance variables and the estimation method for it. In addition, the issues related to the models' construction are explored.

6.2   Stage 1 – A Model with a Single Performance Variable

In most regression analyses within econometrics literature, there is only one variable allowed on the left-side of the model or equation (the dependent variable). As mentioned in chapter 4, the most common used model specification applied in the manufacturing relationship studies is multiple linear regression models. The use of multiple linear regression models may simplify the relationship investigated. It is because these models are based on the assumption of linear effects of independent variables on a dependent variable. It assumes that the effect of an independent variable on the dependent variable is always the same, regardless of the level of other variables (Friedrich, 1982).

In practice, it often happens that the effect of an independent variable on the dependent variable is influenced by the level of another independent variable. In this study, the two independent variables, which are investment and technology usage, are more likely to follow this kind of relationship, which has been discussed in chapter 5. Therefore, multiplicative interaction regression models are developed in this section to test the hypotheses related to the relationships between investment, the use of technology with their interaction term and a performance variable. Whether interaction regression models describe the relationships between investment, technology usage and manufacturing performance better than multiple linear regression models can thereby be discovered. Furthermore, the applicability of multiplicative interaction models in manufacturing relationship studies can be further tested.

6.2.1   Multiplicative Interaction Regression Analysis

In econometrics literature, multiplicative interaction models are normally mentioned with dummy variables, in which one dummy variable is used as a variable interacting with another normal independent variable (Greene, 1993). The multiplicative interaction model with a non-dummy variable as an interacting variable has been discovered in applied econometrics. Multiplicative interaction models are used much less frequently compared with linear regression models in practice due to several issues related to the accuracy of model estimation and result interpretation.

Multiplicative interaction regression analysis is an analysis based on multiplicative interaction regression models. The analysis includes building the interaction model, estimating the coefficients of the model and interpreting results with special attention paid to the coefficients of the variables involved in the interaction term(s). The basic concepts of multiplicative interaction models have been introduced in section 4.2.2. In detail, there are two types of multiplicative interaction models used in the literature related to the different context of the relationships between the factors investigated.

In the first type of interaction model, the independent variables involving the interaction are at the same perceived level, which means that no independent variables in the interaction are treated as moderator variables. If there are two independent variables (x_1, x_2) interacting with each other, the two interacting independent variables' relationships with the dependent variable are both treated equally $(x_1 \rightarrow x_2, x_2 \rightarrow x_1)$. The relationship between either of the two independent variables and the dependent variable is affected by the level of the other one.

The second type of interaction model deals with a different interaction between the independent variables. If we only consider two interacting independent variables, x_1 and x_2, one of the interacting independent variable is treated as a moderator, say x_2. The relationship between x_1 and the dependent variable is actually affected by the level of moderator x_2, not the other way around. The

second type of interaction model is also called moderated multiple regression (MMR; Zedeck, 1971), derived from the work of Saunders (1956).

The two types of multiplicative interaction models reach the same model specification at the end of model construction process but the context of relationships is different under these two types.

Interaction models are all built in a stepwise fashion. Using two interacting variables as an example, there are two steps involved. In the initial step, a linear regression model without an interaction term is constructed. In the second step, the interaction term between the two interacting variables is added into the first step's model. If the second step's model is called a full model, the first step's model, therefore, can be treated as a reduced model. The comparison between the full model and the reduced model is conducted to decide whether an interaction effect of these two variables exists.

A full model contains three effects, the independent variables (x_1 and x_2), and the product of x_1 and x_2 (x_1x_2). A reduced model is constructed by omitting the cross-product (x_1x_2) term and is actually therefore the standard multiple linear regression model. The coefficient of determination (R^2) for the reduced model is then subtracted from the coefficient of determination for the full model. If this difference is statistically significant, the interaction hypothesis is supported (Dunlap and Kemery, 1987).

An alternative way is to compare the adjusted R^2 of the full model with that of the reduced model to decide the existence of the interaction effect. In this method there is no need to test the significance of the difference of adjusted R^2. If there is an increase in adjusted R^2 from the reduced model to the full model, the interaction hypothesis is supported. The two methods of testing interaction effect reach the same conclusion. Most computer programmes provide the calculation of adjusted R^2 rather than the procedure of testing the significant difference between the two R^2s directly. Therefore, adjusted R^2 is used in this research to test

interaction effects.

In this study, neither investment nor technology is treated as a moderator variable. This is because on the one hand the effect of technology usage on performance is likely to be conditioned by the different level of investment. On the other hand, the different level of the technology usage, which is reflected in the technology usage index, can affect the investment level in a company and further on performance. This is due to the need to invest in these technologies at the outset and also to maintain these technologies in use. Therefore, multiplicative interaction models of the first type are developed to test the hypothesised relationships. The model development is presented in section 6.2.4.

6.2.2 Problems in Interaction Regression Models

When two or more independent variables are highly correlated, the model suffers the problems caused by multicollinearity. When the model suffers multicollinearity, OLS can not be directly applied to the model to obtain unbiased estimates. Multicollinearity creates the following problems: (1) rounding error causing less accurate estimations of the model; (2) larger sampling errors or larger standard errors of the estimates of coefficients in the model, and (3) difficult interpretation of regression coefficients (Cronbach, 1987 and Jaccard et al., 1990). In addition, Friedrich (1982) mentioned that "perhaps the most basic criticism of the use of multiplicative terms is that the regression coefficients obtained are hard to interpret.

It is very likely that the interaction term of the two variables is highly correlated with both of the variables involved because the interaction term is the product of the two variables. The strength of the correlations between the variables and their product term depend on these variables' means, standard deviations, and correlation between these variables. The correlations between the variables and their product term can be weak under some circumstances, e.g. the means of variables are approximately zero (Tate, 1984) but they are generally high. Therefore, multicollinearity has to be considered and the problems caused by it have to be solved before interaction regression analysis is applied in this study.

The first problem can be easily solved nowadays due to the high quality of computing tools available, which increase the accuracy by reducing rounding errors, which tend to be larger when two variables multiply with each other, during the calculation process. The second problem is that multicollineary tends to generate either larger sampling errors or larger standard errors. In conventional regression practice, sampling errors or standard errors can be reduced by using larger or more efficient samples and by increasing the numerical accuracy in one's data. However, when multicollineary occurs, larger sampling errors or standard errors can not be reduced by simply increasing sample size (Smith and Sasaki, 1979).

The other problem caused by multicollineary is the difficulty in interpretation of the coefficients of the multiplicative interaction model. The product is often so highly correlated with its constituent variables that it is difficult to separate the multiplicative effect from the additive ones. Whereas the coefficients in an additive model describe the effects of each independent variable on the dependent variable as constant, regardless of the level of the other independent variables, the coefficients in an interactive model describe the effects of each independent variable on the dependent variable as varying, according to the level of the other independent variable. This makes it difficult to interpret the coefficients of a model with a product term involved. However, if one understands that the coefficients in an interaction model are conditional on the levels of the other variable and represents a more detailed relationship, the interpretation of the coefficients can be straightforward. The detail is discussed in the next section.

In order to resolve the problems mentioned above, multicollinearity in interaction regression models has to be reduced. Multicollinearity is a matter of degree because it is impossible there is absolutely no correlation between two variables at all. In order to reduce multicollinearity, the high correlations between the interacting variables and their constituent variables have to be reduced in order to employ an estimator, such as OLS, to obtain unbiased coefficients of the model.

6.2.3   Solutions for the Problems in Interaction Regression Models

When the multicollinearity among the independent variables in a regression model is due to the high correlations of a multiplicative function with its constituent variables, the multicollinearity can be greatly reduced by centralising these variables (Cronbach, 1987 and Smith and Sasaki, 1979).

The centralisation methods proposed by Cronbach and Smith & Sasaki are slightly different but achieve the same purpose. The difference between Cronbach's method and Smith and Sasaki's one is that Cronbach uses the centralised data for all interacting independent variables whether they are in the interaction term or not but Smith and Sasaki use the centralised data only in the interaction term. Because Cronbach' method uses linear transformations of the original model, the models before and after transformation are in one respect the very same model with different ways of describing this dependency of a dependent variable (y) on two interacting independent variables (x_1, x_2). Smith and Sasaki' method only transforms part of the models and shifts the surface compared to the original one. Also, Cronbach's method is more convenient for computing, and therefore it is used for this research.

The advantages of the centralising procedure are that the mean square error remains at its minimum, that the coefficients for other variables in the model are unaffected, the correlations between independent variables and their product terms are reduced without changing R^2 and adjusted R^2, and that the OLS estimates for the original model can be calculated from those for the modified model. Therefore, the problems caused by multicollinearity are avoided.

The Cronbach's centralisation method is presented as follows. Ordinarily, a multiplicative interaction term of two independent variables, say x_1 and x_2, is correlated with x_1 and x_2. When the scale origin is shifted, with the joint distribution of x_1 and x_2 left unchanged, increase in the absolute value of one or both means leads to a decrease in correlations between x_1, x_2 and x_1x_2. Therefore, the modified model is very unlikely to have a substantial multicollinearity

especially when the means of x_1 and x_2 (relative to their standard deviations) are far from zero (Cronbach, 1987).

Lowercase letters are assigned to raw data and capital letters to centralised data and two interacting independent variables are considered in the model. Two regression models describe the same regression surface:

$$y = \alpha_{10} + \beta_{11}x_1 + \beta_{12}x_2 + \beta_{13}x_1x_2 + \varepsilon \qquad (6.1)$$

$$y = \alpha_{20} + \beta_{21}X_1 + \beta_{22}X_2 + \beta_{23}X_1X_2 + \varepsilon \qquad (6.2)$$

Where, μ_{x1}, μ_{x2} are the means of x_1 and x_2, respectively, $X_1 = x_1 - \mu_{x1}$ and $X_2 = x_2 - \mu_{x2}$ and the dependent variable y is not involved in the centralisation. And therefore,

$$X_1X_2 = x_1x_2 - \mu_{x1}x_2 - x_1\mu_{x2} + \mu_{x1}\mu_{x2} \qquad (6.3)$$

After substituting function 6.3, $X_1 = x_1 - \mu_{x1}$ and $X_2 = x_2 - \mu_{x2}$ into model 6.2 and regrouping terms,

$$y = (\alpha_{20} - \beta_{21}\mu_{x1} - \beta_{22}\mu_{x2} + \beta_{23}\mu_{x1}\mu_{x2})$$
$$+ (\beta_{21} - \beta_{23}\mu_{x2})x_1 + (\beta_{22} - \beta_{23}\mu_{x1})x_2 + \beta_{23}x_1x_2 \qquad (6.4)$$

After using OLS to estimate the modified model 6.2, the coefficients in the original model 6.1 can be calculated using the transformation from the ones in the modified model 6.2. The formulae can be obtained by comparing 6.1 with 6.4.

$$\alpha_{10} = \alpha_{20} - \beta_{21}\mu_{x1} - \beta_{22}\mu_{x2} + \beta_{23}\mu_{x1}\mu_{x2} \qquad (6.5)$$

$$\beta_{11} = \beta_{21} - \beta_{23}\mu_{x2} \qquad (6.6)$$

$$\beta_{12} = \beta_{22} - \beta_{23}\mu_{x1} \qquad (6.7)$$

$$\beta_{13} = \beta_{23} \qquad\qquad (6.8)$$

As far as the interpretation of coefficients in a model is concerned, they are quite different between a multiple linear model and a multiplicative interaction model. In a multiple linear regression model with two independent variables, $y = \alpha_0 + \beta_1 x_1 + \beta_2 x_2$, β_1 and β_2 estimate the *general* trends of change in y with changes in x_1 and x_2 across all levels of x_2 and x_1, respectively because the model represents a flat surface. In a multiplicative interaction model, $y = \alpha_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_1 x_2$, without any transformation of variables involved, β_1 and β_2 estimate the *particular* trends of change in y with changes in x_1 and x_2 when x_2 and x_1, respectively, equal to zero because the model represents a curved surface. Coefficient β_3 describes how bent the surface is, with a small value denoting a relatively flat surface and a large value denoting a relatively curved one. If the ranges of the independent variables do encompass zero, there is no problem in interpreting the coefficients. But if they do not, then the coefficients will be extrapolations beyond the "observed range of experience". It then makes more sense to evaluate the conditional relationships only within the observed range of experience (Friedrich, 1982).

In this study, the independent variables of the use of technology and investment are very unlikely to cover zero. The coefficients of the centralised model are actually more meaningful. It is because they represent the changes of an independent variable on the dependent variable when the other independent variable is equal to its mean. These effects are also called "main effects". "A main effect is defined as the simple main effect of a variable when the other variable is equal to its own mean" (Tate, 1984). Therefore, the coefficients of the centralised models should be used for interpretation of the main effect and the effects of the variables at other points can be calculated if needed.

6.2.4   The Models Developed for a Single Performance Variable

Because the hypotheses set up for this research involve the investigation of

individual effect of either investment or technology usage on manufacturing performance, the models are developed in three steps. In step 1, independent variables, investment and the use of technology, are individually regressed against the dependent variable, performance (the relationship described at figure 5.11a). The effect of investment and the use of technology together on performance are tested in step 2 (the relationship described at figure 5.11b). Adding a multiplicative interaction term of two independent variables into the second step model forms the step 3 model (the relationship described at figure 5.11c).

$$\text{Step 1: } y_t = \alpha + \beta_1 x_{1, t-m} + \varepsilon \tag{6.9}$$

$$y_t = \alpha + \beta_1 \Sigma x_{1, t-m} + \varepsilon \tag{6.10}$$

$$y_t = \alpha + \beta_2 x_2 + \varepsilon \tag{6.11}$$

$$\text{Step 2: } y_t = \alpha + \beta_1 x_{1, t-m} + \beta_2 x_{2,t} + \varepsilon \tag{6.12}$$

$$y_t = \alpha + \beta_1 \Sigma x_{1, t-m} + \beta_2 x_{2,t} + \varepsilon \tag{6.13}$$

$$\text{Step 3: } y_t = \alpha + \beta_1 x_{1, t-m} + \beta_2 x_{2,t} + \beta_3 x_{1, t-m} x_2 + \varepsilon \tag{6.14}$$

$$y_t = \alpha + \beta_1 \Sigma x_{1, t-m} + \beta_2 x_{2,t} + \beta_3 \Sigma x_{1, t-m} x_2 + \varepsilon \tag{6.15}$$

Where y_t is performance variables in the year t, $x_{1,t-m}$ represents investment values in the year $(t-m)$, $m = 0, 1, 2, 3...$, $\Sigma x_{1, t-m}$ represents a cumulative investment from $t-m$ to t and x_2 represents index of the use of technology in the period; α, β_1, β_2, and β_3 are regression coefficients; and ε is a disturbance term of the models. Even though the subscripts are not used to distinguish the coefficients in each model, it is obvious that the coefficients in each model represent different values related to the model.

The multiplicative interaction effect of investment and the use of technology on manufacturing companies' performance is tested by comparing the model in step 3 with the model in step 2, for investment in a single year and in cumulative format. If there is an increase in adjusted R^2 from the model 6.12 or 6.13 in step 2 to the model 6.14 or 6.15 in step 3, the hypothesis on the multiplicative interaction

effect of investment in a single year or cumulatively and the use of technology is supported.

Model 6.9 is used to test hypothesis 1. Model 6.10 is used to test hypothesis 2. Hypothesis 3 is tested by model 6.11. Model 6.12 in step 2 and model 6.14 in step 3 together are used to test hypothesis 4. Model 6.13 in step 2 and model 6.15 in step 3 together are used to test hypothesis 5.

Ordinary Least Squares (OLS) method is used for the model estimations. Limdep (version 6.0), which is an econometric software tool which allows users to modify the available regression models through programming, is used to realise and run the developed models including centralising the independent variables involved in the interaction (Greene, 1991). An example of model programme developed using Limdep is given in appendix 6.

The question may arise that panel data estimation should be considered when a panel data set is available. The two independent variables hypothesised are investment and technology index. Without considering technology index, the database used for testing hypotheses is designed in a panel. However, a single technology index is available for the whole period but not one for each year. Therefore, strictly speaking, the data used in this research are not a panel. The panel data estimate method has been investigated but however the limitation of the data set did not allow the further exploration. It may possibly investigate investment alone using panel data estimator, fixed or random effects regression models. However, there are several further reasons why panel data estimation is not used for the developed models in this research related to effects of investment on performance, besides the factor of no time series data of the use of technology.

Firstly, the research is intended to discover the trends of the two periods rather than to treat the periods as a whole. The panel data estimation intends to generate a set of the coefficients representing the characteristics of the period, which the panel covers. Secondly, the delay effects of the investment (an independent

variable) and cumulative investment on the performance are hypothesised. The number of years cumulated investment has to be explored to carry out the modelling related to cumulative investment. After cumulating investment variables, the panel for investment variable has been lost, corresponding to performance variables, which are not cumulated. Finally, the sample size would be very small if the whole panel had been considered to be used because the missing data occurred in this database across companies and through years, which causes the panel data to be unbalanced. There are programs (such as Limdep) which can apparently be used for unbalanced panel data. However, this refers to different numbers of dimensions of variables and therefore it is different from the concept of an unbalanced panel used in this research, which is related to missing data (Greene, 1991). Very recently (after this study's modelling had been conducted), Doornik et al. (1999) have developed the Dynamic Panel Data (DPD) estimation, which can be used to deal with unbalanced panel data, which shares the same concept with this research, missing data. However, the method still treats a period as a whole by generating a set of coefficients of the model to represent the whole period, therefore, it is not suitable for this research. It can not be denied that the panel data estimation is a very valuable method and has to be considered when the data is arranged in a panel. However, it can not be applied in this research.

6.3   Stage 2 - A Model with Two Performance Variables

The performance analysis of organisations is becoming more complex as single-valued determinations of financial performance (e.g. return on investment) are replaced by Balanced Scorecard approaches (Kaplan & Norton, 1992, 1993 and 1996). Most statistical techniques which have been used in published work in this field have concentrated on a single performance variable, or a combined index based on predetermined goal weighting of a set of performance variables.

When more than one dependent variable is investigated, two completely separate models or simultaneous equations or seemingly unrelated equations can be used based on the models provided in econometrics. However, these models can only include one dependent variable in each equation. If these dependent variables are

joint products of the same set of independent variables, a model constructed which includes all the dependent variables is desirable for describing the relationships between these dependent variables and the same set of independent variables. Multivariate regression analysis, which can be included in econometrics but has its own specified areas, provides the basic theoretical knowledge to build several dependent variables in a single model. In practice, models including more than one dependent variable are rarely used, even though there are many situations in real life requiring the consideration of several dependent variables as joint products. This may be because estimating methods of multivariate models are still in their infancy or the explanation of the models' coefficients seems difficult, especially for the coefficients of the dependent variables.

In this section, the models including two dimensional performance variables are developed. The developed models are used to test the hypotheses 6 and 7, which propose two dimensional performance variables, profit and growth. Whether these two dimensions of manufacturing performance are joint products of investment and technology usage is investigated or tested by the model. Also, the developed model contributes to methodology development by providing an alternative tool for efficiently studying the manufacturing relationships involving two or more dimensional performance measures in practice.

6.3.1   Multiple-Outputs Models and Canonical Analysis

The literature in econometrics and multivariate analysis has addressed the modelling of more than one dependent variable in a single model (Chatfield & Collins, 1980, and Vinod, 1968, 1969, 1976). These models are also named multiple-outputs models. Multiple-outputs models were developed based on canonical correlation analysis, which is an analysis tool provided in multivariate analysis literature. In canonical correlation analysis, a linear combination of X_1, which is dependent, is found in a linear-regression sense, on the values of X_2, which is independent. Specifically, if the total number of the components in X_1 and X_2 is equal to p, there are q components in X_1 (X_1, X_2...X_q), and $U = a^T X_1$, we wish to choose a vector a so that in a regression of U on X_2 (X_{q+1}, X_{q+2}...X_p), the variance ratio for testing the significance of the regression is a maximum. The

formula of the variance ratio for testing the significance of the regression is given by Chatfield and Collins (1980, page 168).

Multiple-outputs models were developed initially for econometric problems and their applications have been discovered in educational relationship studies (Chizmar & Zak, 1983, Arnold et al., 1996 and Tofallis, 1997a). No applications of the multiple-outputs model have been discovered in manufacturing relationship studies.

Employing more than one variable to measure manufacturing performance can be more meaningful in many aspects in practice because it provides for emergent as well as intended contributions to performance. Multiple-outputs modelling may become a useful tool to model more than one dimensional performance measure for companies to measure their success from many perspectives.

When more than one dependent variable is considered in relationships, there are three different situations. In each situation, a different form of model is required to describe the relationship and therefore a different modelling technique is applied in order to build the model to represent the relationship most appropriately.

If two performance variables are products produced by separate practices (inputs) and are completely independent, separate models should be employed for each performance measure.

$$y_1 = f(x_1, x_2, ... x_n) \qquad (6.16)$$

$$y_2 = g(x_1, x_2, ... x_n) \qquad (6.17)$$

The above two models represent two dependent variables which are completely independent to one another with n inputs (n can be a different number in each model).

If the two performance variables are produced simultaneously and either of them can be also a cause (input) of the other, a simultaneous model, which includes two equations with either dependent variable in one model as an independent variable in the other one, should be used.

$$y_1 = f(y_2,\ x_1, x_2, \dots x_n) \qquad\qquad (6.18)$$

$$y_2 = g(y_1,\ x_1, x_2, \dots x_n) \qquad\qquad (6.19)$$

A single model including the two performance measures as dependent variables should be constructed to estimate the relationship if the two performance variables are joint products of the independent variables (inputs). In the last case, the model is defined as below in a general format.

$$f(y_1,\ y_2) = g(x_i) \qquad\qquad (6.20)$$

The function used for both sides of the equation can be in many forms, e.g. linear combination, production function (which can be converted into a linear model using log transformation) and linear combination including product-term between variables. There is no definitive answer as to which is the best form of functions for a certain situation, and the choice is based mainly on the literature or experimental suggestions.

It is almost impossible that the two dependent variables considered in a study are completely independent of each other. It is also difficult to have a clear cut perception that would enable one to judge whether the two dependent variables are produced simultaneously or are joint products of the independent variables (inputs). A concept called "input exhaustion" introduced by Brown and Saks (1980) can be used to help the judgement. It indicates the extent to which an increase in input applied to one output reduces the amount of that input available to produce other outputs. Complete input exhaustion occurs when outputs are

independently produced. If, however, using an input to produce one output does not reduce its availability for producing other outputs, then the input is shared and the outputs are jointly produced. It is a matter of degree that using an input to produce one output does not reduce its availability for producing other outputs.

Output 1 → 2 → Output 2

Input 1, Input 2
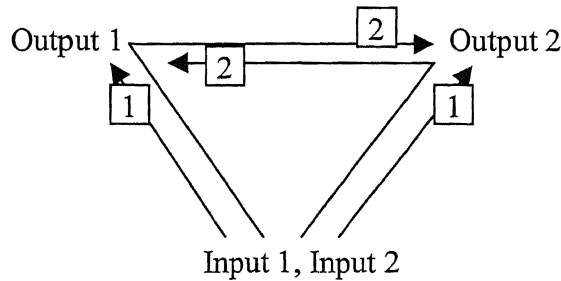
Figure 6. 1   Illustration of the Degree to which Two Outputs Shared by Two Inputs

Figure 6.1 provides an illustration of the relationships between two outputs and two inputs. There can be two different types of processes involved for outputs generated from inputs. One is described as process 1 and the other one process 2 in figure 6.1. In process 1, the resources are not shared and the two outputs are independent produced, in which an increase in one input applied to one output reduces the amount of that input available to produce the other output. In process 2, the resources are shared, in which an increase in one input applied to one output is also available to produce the other output. If process 1 does not exist for the inputs and outputs relationship, the resources are totally shared. Otherwise, the resources are not shared at all. In between, it is a matter of the degree between the shared and non-shared resources by the outputs.

In this study, the two dimensions of performance investigated are RoS and value added growth. It is unlikely that the benefit on 'return' by investment and technology usage can reduce the availability of investment and technology usage to contribute to value added growth. RoS and growth are more likely two joint products through the same process rather than through two independent processes. In most times, a company with high return has a better chance to grow than the one which has a low return or is unprofitable. Therefore, investment and the use of technology can be the shared resources for both return and growth in a

company. Return and value added growth are proposed as two joint products of investment and technology usage in this research and a model is developed to test the hypotheses related to it.

6.3.2   Maximum Correlation

A concept which has been established is that different models require different techniques to estimate the coefficients in the models. *OLS* is an appropriate estimator for the models of multiple products produced independently, such as model 6.16 and model 6.17. *2SLS* is appropriate for the models with multiple products produced simultaneously, such as model 6.18 and model 6.19. If outputs are jointly produced (model 6.20), neither *OLS* nor *2SLS* is appropriate because for both techniques, a single equation can have only one dependent variable.

Based on canonical correlation analysis (Chatfield and Collins, 1980 and Anderson, 1984), a method called maximum correlation is developed to be used to estimate the coefficients of multiple-outputs models such as model 6.20. If there are x_i inputs, $i = 1, 2, ...n$, and y_j outputs, $j = 1, 2, ...m$, the linear combination of $X = \Sigma \alpha_i x_i$ for inputs and $Y = \Sigma \beta_j y_j$ for outputs can be found to maximise the correlation between X and Y by changing the coefficients in the linear combination.

If there are two inputs (x_1 and x_2) and two outputs (y_1 and y_2), the model in linear combination for the both sides will be:

$$\beta_1 y_1 + \beta_2 y_2 = \alpha_0 + \alpha_1 x_1 + \alpha_2 x_2 + \varepsilon \qquad (6.21)$$

The approach is to set up $Y = \beta_{11} y_1 + \beta_{22} y_2$ and $X = \alpha_{11} x_1 + \alpha_{22} x_2$, and then maximise the correlation between X and Y to discover the optimum solution for the model, under certain constraints if required. For example, the coefficients should be set positive if only positive coefficients are meaningful for the situation investigated. The coefficients (β_{11}, β_{22}, α_{11} and α_{22}) estimated by the maximum correlation method have to be converted into the coefficients in the original model

(6.21). Because a correlation between two variables mostly refers to a linear relationship between these two variables, a simple linear model $Y=A+BX$ is used to convert the coefficients. The maximum correlation method decides X and Y based on the estimated coefficients on β_{11}, β_{22}, α_{11} and α_{22} and the data on x_i and y_j. Then an OLS method is used to estimate A and B. Afterwards, the following equations are used to obtain the coefficients of the original model:

$$\beta_1 y_1 + \beta_2 y_2 = \beta_{11} y_1 + \beta_{22} y_2$$

$$\alpha_0 + \alpha_1 x_1 + \alpha_2 x_2 = A + B(\alpha_{11} x_1 + \alpha_{22} x_2)$$

The coefficients of the dependent variables are the same as those estimated from the maximum correlation method, but the coefficients of the independent variables have to be calculated using the following equations:

$$\alpha_0 = A; \ \alpha_1 = B \times \alpha_{11}; \ and \ \alpha_2 = B \times \alpha_{22}$$

In a traditional regression model, which has only one dependent variable in one model, the coefficient of the dependent variable is actually equal to unity (value 1). The model represents the same function if both sides are multiplied by any constant. This could lead to unlimited parallel sets of answers for a model. For this reason one of the coefficients of the dependent variables should be set to unity for the model with joint products before estimating the coefficients, in order to obtain a unique set of answers.

6.3.3   The Model Developed for Two Performance Variables

In this research, the following multiple-outputs model has been developed to test the hypotheses 6 and 7. A multiplicative interaction term between investment and technology usage is included in the right side of the model to test the interaction effect of investment and technology usage on the two dimensional performance measures. Therefore, the model is

$$\beta_1 y_1 + \beta_2 y_2 = a_0 + \alpha_1 x_1 + \alpha_2 x_2 + \alpha_3 x_1 x_2 + \varepsilon \tag{6.22}$$

Where, y_1 and y_2 represent the performance variables-return and growth respectively; x_1 represents the most highly positive correlated form of investment (single year with and without time lag and cumulative), which is discovered in stage 1, and x_2 stands for technology index; β_1, β_2, α_1 a_2 and a_3 are coefficients of the model and ε is a disturbance term.

The centralisation of the two independent variables has been conducted to solve the problems caused by multicollinearity before using maximum correlation to estimate the coefficients of the model. In maximum correlation, one of β_1 and β_2 has to be set to unity. It does not matter whether β_1 or β_2 is set to 1 if the two dependent variables are the products of the independent variables, because the results of the estimations of coefficients should be the same. However, the results are not the same if only one of the dependent variables is actually the product of the independent variables. In this case, the coefficient of the one which is affected by the independent variables should be set to unity in order to obtain the convergent estimation of the coefficients in the model. To test this, both alternatives need exploration. The details for the selection and results of the model 6.22 are presented in the second part of chapter 7.

Excel is used to set up the data for maximum correlation. The function of Solver in Excel (Tofallis, 1997b) is used to estimate the coefficient based on the goal of maximum correlation and the constraints, which all the coefficients are positive, are added into the model for the meaningful solution. The reason for setting up all coefficients to be positive is to discover whether positive effects of the factors investigated on performance variables possibly occurred in the past. If only non-significant model is obtained under this constraint, it means that no positive relationship between these factors can be found. Otherwise, the estimated positive coefficients satisfying model with significant r^2 can be accepted. An example of the application is given in appendix 7.

In one dependent variable regression, in order to decide the better model specification between two models with different number of independent variables, a significance test on the difference between the two r^2s or a comparison of the two adjusted r^2s can be used. The principle can be applied to the multiple-outputs models as well to judge whether the model specification improves by adding one more dependent variable, under the premise of literature suggestions. If the model with multiple-outputs has a significant r^2, which is significantly higher than the one in the single output models (using statistic t-test or F test on the difference of two r^2s), we can say that the multiple-outputs hypothesis is supported.

All the methods have their limitations. It applies to maximum correlation method as well. It is relative newly developed method with very limited applications. There are no further investigations or discussions on the conditions of using this method, such as a certain distribution required for variables or the requirements for disturbance term in the literature. The method ensures the maximised correlation between all the inputs in linear combination and all the outputs in linear combination by changing the weights of the inputs and outputs. However, we do not know whether the best fit of the data is obtained, in which the sum of the squares of the distance between the estimated value and the actually value is minimised.

In addition, there are no available packages to systematically generate the relevant results related to the methods. Using Excel spreadsheet and Solver, the estimation can be obtained for the coefficients of the multiple-outputs model but without providing the further analysing information on the results, such as significance tests like other matured estimating methods in statistical or econometric packages. However, we still can not deny this method as an estimating technique for multiple-outputs model and this method is used in this research. It is because there is no other method available which can replace the maximum correlation method to estimate the coefficients for the multiple-outputs model and there is fundamental underpinning of the maximum correlation method, which is canonical correlation analysis.

6.4   Summary

In this chapter, the models which can be used to test the hypothesised relationships have been developed in the two stages.

In stage 1, the multiplicative interaction regression models have been constructed to test the hypotheses considering a single performance measure at a time. The issues related to multiplicative interaction models have been discussed. The problems caused by multicollinearity due to multiplicative terms in the model have been presented. The centralisation method which can be used to reduce nulticollinearity has been introduced and applied in this research before using an OLS to estimate the coefficients of the models. Limdep is used for this stage's modelling.

In stage 2, the multiple-outputs model is built to test the hypotheses on the two dimensions of performance. The maximum correlation method used to estimate the coefficients of the multiple-outputs model has been presented. Excel has been used for this stage's modelling.

The data has been applied in these two stages' models and the results and the interpretations are presented in the next chapter.

Chapter 7   The Results and Interpretations

7.1   Introduction

This chapter presents the findings on the relationships between investment and the use of technology and manufacturing performance generated based on the developed models presented in chapter 6 and the UK database described in chapter 5. These findings are arranged in two parts, according to the two types of the developed models.

In part 1, the results related to the single performance variable models are presented. The effects of investment, technology usage and their interaction on manufacturing performance are tested and presented in two time periods, the 1980s and the early 1990s. The findings in these two periods are compared to discover the changes on the relationships from the 1980s to the early 1990s.

Part 2 provides the results related to the two-dimensional performance model. The joint products of RoS and value added growth produced by cumulative investment, technology usage and their interaction are tested using the 1980s data and the findings are presented. The reason that only the 1980's data is used for the multiple-outputs model is given in section 7.3. The findings in part 1 have informed the selection of the most appropriate form for investment and performance measure on return for testing the hypotheses related to the multiple-outputs model.

The interpretations of these results on the relationships between investment, technology usage and their interaction on single and two-dimensional performance measures are provided. The interpretations are based on the modelling results. However, the further discussion of these findings with consideration of other factors identified in the theoretical studies including external ones to firms and their influences on the researched relationships is held over till Chapter 8. Finally, the findings on the developed methods for modelling manufacturing relationships are given.

7.2   Part 1 – Findings on One Performance Variable Model

According to the availability of the performance variables in the database and the performance variables and the performance measurement systems reviewed in section 2.3, especially the performance hierarchical framework, three performance variables have been chosen to be used in this research. Two 'return' performance variables, which are RoA and RoS, are used to represent the highest level of financial performance. As an efficiency performance measure, TFP is the most appropriate one to stand for the efficiency of a company as a whole comparing with other efficiency measures, such as employment efficiency and capital efficiency. It is because that TFP stands for the highest level of efficiency measures compared with the other ones mentioned in figure 2.5.

Due to the structure of the database, the models are run for the two different periods with different sample sizes, one from 1979 to 1988 (also called 'the 1980s') and the other one from 1989 to 1995 (also called 'the early 1990s').

7.2.1   Effect of Investment in a Single Year and Technology Usage and Their Interaction on Performance in the 1980s

The characteristics (mean, minimum, median, maximum, standard deviation and sample size) of the sample for this period have been given for several representative variables in appendix 8. Two are performance variables, profitability (RoS%) and efficiency (TFP). Two are practice variables, investment% and technology index. Investment and RoS are scaled using their percentage values for the consistency of calculation with the other variables.

The correlation matrices of investment of each year and the use of technology index of the period with the three performance measures (RoS, TFP and RoA) in each year from 1979 to 1988 are given in table 7.1.

r	RoS79	RoS80	RoS81	RoS82	RoS83	RoS84	RoS85	RoS86	RoS87	RoS88
Tech.	-0.12	-0.03	0.14	**0.22**	0.10	**0.21**	**0.20**	0.12	**0.21**	**0.23**
Inv79	**-0.69**	**-0.46**	0.01	-0.00	-0.06	-0.04	-0.05	-0.06	-0.02	-0.12
Inv80		**-0.31**	-0.00	0.06	0.10	0.09	0.08	0.09	0.07	0.08
Inv81			**-0.53**	-0.07	0.04	0.09	0.10	0.10	0.14	0.26
Inv82				**0.19**	**0.19**	**0.29**	**0.24**	**0.30**	**0.25**	**0.33**
Inv83					**-0.45**	0.04	-0.07	-0.02	0.12	0.34
Inv84						**-0.18**	-0.02	-0.01	-0.10	-0.13
Inv85							**-0.24**	**0.35**	**-0.31**	0.08
Inv86								**-0.62**	-0.08	0.06
Inv87									-0.00	-0.02
Inv88										**-0.40**

Bold number: the significant correlation coefficients at the level 10%.

r	TFP79	TFP80	TFP81	TFP82	TFP83	TFP84	TFP85	TFP86	TFP87	TFP88
Tech.	0.02	-0.04	0.08	0.00	0.06	0.10	**0.19**	**0.18**	0.07	0.13
Inv79	-0.16	-0.01	-0.06	-0.12	-0.03	0.00	-0.07	-0.11	-0.19	**-0.26**
Inv80		-0.15	-0.11	-0.16	-0.10	0.01	-0.05	-0.09	-0.19	-0.18
Inv81			**-0.27**	-0.09	-0.01	0.11	0.19	0.13	0.19	-0.01
Inv82				-0.09	-0.10	-0.01	-0.08	-0.18	-0.13	0.08
Inv83					**-0.23**	**0.18**	0.02	-0.04	-0.06	0.18
Inv84						**-0.15**	-0.11	-0.15	**-0.22**	-0.17
Inv85							-0.11	-0.08	-0.18	0.05
Inv86								**-0.17**	-0.03	-0.06
Inv87									-0.07	0.01
Inv88										**-0.30**

Bold number: the significant correlation coefficients at the level 10%.

r	RoA79	RoA80	RoA81	RoA82	RoA83	RoA84	RoA85	RoA86	RoA87	RoA88
Tech.	-0.12	-0.12	-0.06	0.11	0.07	0.07	0.09	0.10	**0.17**	**0.11**
Inv79	-0.24	**-0.34**	-0.15	-0.04	-0.16	-0.13	-0.13	-0.15	-0.10	-0.21
Inv80		-0.22	-0.02	0.02	0.06	0.10	0.09	0.08	0.05	0.01
Inv81			-0.17	-0.12	-0.03	0.06	**0.36**	**0.24**	**0.50**	-0.02
Inv82				0.08	0.02	0.10	0.05	0.15	0.01	-0.01
Inv83					0.01	0.02	-0.08	-0.03	-0.03	0.25
Inv84						**-0.20**	-0.04	-0.06	-0.07	-0.12
Inv85							-0.11	0.13	-0.16	0.06
Inv86								**-0.21**	-0.07	-0.00
Inv87									0.00	0.11
Inv88										-0.30

Bold number: the significant correlation coefficients at the level less than 10%.

Table 7. 1   Correlation Matrices of Investment, Technology Usage and RoS, TFP and RoA for the Period from 1979 to 1988

Because the hypotheses of the study is on the effects of investment, along with technology usage, on the same year or later year(s) performance but not the

effects of performance on the same year and the later year(s)' investment, only the correlation coefficients presented in upper right sectors are relevant for this study, as shown in table 7.1. The effects of performance on investment and technology usage is not considered in this research and is not supported by the data either (not reported here).

For the three matrices in table 7.1, the correlation coefficients related to RoS show the most consistently significant results during this ten years' period compared with the ones related to RoA and TFP. The data in this period did not show much significant relationships between investment, technology usage and RoA or TFP. It can be explained and understood by looking at the formulae of these variables. RoA is calculated by profit before tax divided by total assets, which increases when investment is greater than depreciation. TFP is calculated by value added divided by employment and capital cost, which increase when investment in new capital occurs. On the one hand, the gain on 'Return' or value added by investment has to outweigh the increased cost of investment on capital adequately to show significant positive relationship between investment and RoA and TFP. On the other hand, the loss on 'Return' or value added has to be enough to allow negative relationships between investment, and RoA and TFP to occur, compared to the increased capital cost due to investment. Otherwise, no significant relationships between investment and RoA or TFP are showed, which is the case in the 1980s. RoS more likely depends on the increase or decrease of profit before tax if sales are at the same level within the normal economic scale. Because only RoS showed a consistent relationship with investment during the 1980s, it is used for the modelling of one performance variable models.

In this section, the results of investment in a single year with and without time lag and technology usage as well as their interaction on RoS have been reported. Table 7.2 presents the basic findings on the three-step regression models with investment employed in a single year without time lag.

RoS	Model						
	6.9	**6.11**	**6.12**		**6.14**		
	Inv.	Tech.	Inv.	Tech.	Inv.	Tech.	Int.
88	—	+	—			+	
87		++		++		++	
86	—		—	++	—	++	++
85	—	++	—	++	—	++	
84	—	++	—	++	—	++	++
83	—		—	++	—	++	
82	++	++	++	+		++	
81	—		—	++	—	++	++
80	—		—				—
79	—		—		—		—

+, –: Significantly positive or negative at 10% level
++, —: Significantly positive or negative at 5% level
☐: The model is not significant at 10% level

Table 7. 2   The Significance of the Coefficients of the Models in a Single Year's Investment without Time Lag (When m = 0) in the 1980s

In table 7.2, 'Inv.' represents investment percentage, 'Tech.' represents technology index, 'Int.' stands for the interaction term between investment and technology usage. These abbreviations are used throughout tables in this chapter.

The significance of the coefficients in each model from 1979 to 1988 is reported in table 7.2 to provide an overall and straightforward perception of the findings on the effect of investment in a single year without time lag, the use of technology, and their multiplicative interaction effect on manufacturing performance measured by RoS. The values of the coefficients of the variables of the models are provided in appendix 9.

When the model is a simple linear regression model which involves only one independent variable, the significance of the regression coefficient is equivalent to the model significance. Model 6.9 and 6.11 are two simple linear models to test the effect of either investment or the use of technology alone on manufacturing performance by RoS. Without the consideration of the availability of better model

specification for the relationships between these two factors and manufacturing performance, the following interpretation for model 6.9 and 6.11 is valid.

Model 6.9 in all the years during this period is significant at the 0.05 level except for the one in 1987, which is not significant even at the 0.1 level. The model generates very consistent results for investment in a single year on manufacturing performance measured by RoS during this period. The significantly negative coefficients of investment in a single year without time lag on the same year's RoS throughout the period, except for the investment in 1982 being a totally exceptional case with significant positive effect and the investment in 1987 with no significant result.

The negative coefficients of model 6.9 suggest that investment by itself tends to show a negative relation to the RoS in the same year. This supports the first part of hypothesis 1 that the performance decreases in the year of investment because of the increased costs associated with the launch expenses of investment in that year. However, it does not suggest that investment *per se* is of no value in improving performance. The benefit of investment (especially a long-term investment) is unlikely to be gained in the same year and it normally takes years to be fulfilled. A complete conclusion about investment cannot be drawn until the results on the effects of investment with time lags and in a cumulative format on manufacturing performance are explored and presented. However, it does show that during this period, rapid payback from investment was generally not possible.

The effect on manufacturing performance of the use of technology alone is tested by model 6.11. The results of the coefficients support the hypothesis that the use of technology has a significantly positive relation to the RoS for half of the years and has no negative effect at all during this ten years' period. If one looks at the upper half period which is from 1984 to 1988, the use of technology has a significant positive effect on manufacturing performance in most of the years. Because the use of technology is measured by an overall index which incorporates the degree to which the technology represents the state of the art, it suggests that

the value of new technology was less unambiguous from around the 1984 date. Prior to this point, new technology was more problematic than had been imagined in the early 1980s (Hamblin, 1990).

In order to discover a more appropriate form of the relationship between these factors, model 6.12 includes both investment in a single year without time lag and the use of technology as the two independent variables. Model 6.12 employs a multiple linear model to investigate the relationship between investment, the use of technology and manufacturing performance under the assumption of no interaction effect between investment and the use of technology. There are no changes at all on the significance signs of the coefficients related to the investment (significance levels may slightly change – see appendix 9, but still in the same range), comparing with model 6.9. However, the use of technology in model 6.12 shows a higher percentage positive significance during these ten years than model 6.11 (20% increase). The decision on which model has a better specification for the relationship is going to be made after presenting the step 3 model and the comparison between them. Whether the model, including both the factors and maybe more, such as the interaction term between them, represents the relationship most appropriately can be answered.

Model 6.14 in table 7.2 reports the results with the consideration of the interaction effect of investment in a single year without time lag and the use of technology on manufacturing performance measured by RoS. All the significant coefficients of investment in a single year without time lag are negative, all the significant coefficients of the use of technology are positive and the significant coefficients of interaction term have a mixture of both signs. Comparing with the results of model 6.12, the investment has less significant negative cases and the use of technology has more significant cases in model 6.14. The positive effect of 1982's investment on the same year's RoS disappears in model 6.14. The significant coefficients of interaction term occurs for the half of the cases with slightly more positive signs than negative signs. This only implies that the interaction effect between investment in a single year without time lag and the use of technology

may contribute to RoS in certain years but not in all the cases during this period. However, the decision on which model describes the relationship most appropriately can not be made based on the information presented so far.

In order to decide the most appropriate model specification for the relationship between investment in a single year without time lag and the use of technology and manufacturing performance by RoS, the comparison of R^2 or adjusted R^2 are required. As mentioned in chapter 6, adjusted R^2 is used to decide the appropriate model specification rather than testing the significance of the difference between R^2s.

RoS	Model 6.9 (Inv.) $A\text{-}R^2$	Model 6.11 (Tech.) $A\text{-}R^2$	Model 6.12 (Inv.+Tech.) $A\text{-}R^2$	Model 6.14 (+Int.) $A\text{-}R^2$	Increment by Int. $\Delta A\text{-}R^2$
88	0.147	0.039	0.162	0.157	-0.005
87	-0.008	0.036	0.016	0.022	0.006
86	0.377	0.008	0.390	0.416	0.026
85	0.051	0.042	0.108	0.107	-0.001
84	0.026	0.040	0.068	0.148	0.080
83	0.201	0.001	0.222	0.231	0.009
82	0.063	0.040	0.084	0.094	0.010
81	0.271	0.012	0.325	0.632	0.307
80	0.105	-0.010	0.095	0.143	0.048
79	0.461	0.008	0.460	0.571	0.111

☐: The model is not significant at 10% level

Table 7. 3   Adjusted R^2 of the Three Stages' Models and the Increment of Them by Interaction, When m = 0, in the 1980s

Table 7.3 reports adjusted R^2 of the three-step regression models and the increases of adjusted R^2 values from model 6.12 to model 6.14. Three decimal places are used for the comparison between adjusted R^2s because most of them are small but significant. The R^2s are slightly higher than their adjusted R^2s but are still small but significant. At the microeconomic level, the relationships between the factors investigated are less steady compared with those at the macroeconomic level because there are many more uncontrollable factors at the microeconomic level, such as the industrial and companies' environment, discussed in chapter 2. A high correlation coefficient (near ± 1) is never discovered at the manufacturing

company or industry level. When the relationship has significant R^2, it implies that the relationships described in the models happen not by a coincidence and mean something. Dougherty (1992, page 262) particularly mentions "Those who are new to regression analysis tend to develop an R^2 fixation and believe that, if R^2 is high, the equation is well-specified and that, if it is low, the regression has been a waste of time. Both conclusions are false." He further states using his own case that a significant but small coefficient means it counts a tiny proportion of the total variance, but nevertheless it is significant and the effect of the factor on the dependent variable has to be taken into account.

In order to decide whether the performance measured by RoS is driven by both the factors, we need to compare adjusted R^2 of model 6.9 and 6.11 with 6.12. There are generally notable increases of adjusted R^2 from model 6.9 or 6.11 to 6.12 in each years during this period with a couple of exceptions. This implies that model 6.12 is generally better specified than model 6.9 or 6.11, i.e. that the performance measured by RoS was driven by both the factors during this period.

However, whether there is an interaction effect between investment in a single year without time lag and the use of technology on manufacturing performance, the comparison between adjusted R^2s of model 6.12 and model 6.14 is conducted and reported in the last column of table 7.3. The model 6.14 includes the interaction effect of investment and the use of technology on manufacturing performance. Except for 1987, model 6.14 for every year is significant at the 1% level. In year 1987, the model is not significant even at the 10% level ($p<0.13$). Even though there are significant interaction effects only for half of the years under study (three positive and two negative), eight of the ten years' interaction models have a higher adjusted R^2, which supports the multiplicative interaction of investment, in a single year and without time lag, and the use of technology affecting manufacturing companies' performance.

Increased adjusted R^2 means that this addition of the multiplicative-interaction term increases the level of explanation of the relationships. The average increase

of R^2 in this ten years is 0.064 (not reported in the table 7.3) and 0.059 for adjusted R^2, which means that the interaction model (model 6.14) explains about an average of 6.4 percent more of the variation in performance than does the additive model (model 6.12). Because there were no effects of the use of technology alone on performance in the early years of this ten years' period, the two negative significant regression coefficients related to the interaction terms cannot be fully explained. There are suggestions that in the earliest years of the period the new technology was not delivering adequate benefits and that therefore more spend on new technology made performance disproportionately worse. In later years this situation appears to have reversed, but not to the extent that every single interaction term is significantly positive.

Investment in a single year did not show benefit on the same year's performance measured by RoS. It did not bring benefits to the same year's efficiency measured by TFP either (see table 7.1), even though the TFP was not used to study interaction effects during the 1980s due to inconsistency of correlation coefficients between investment and TFP. However, investment may contribute to performance in the later years. The following table reports the results of the significance of investment in a single year but with time lag from 1 to 3 years and the use of technology on manufacturing performance measured by RoS.

RoS	Model																	
	6.9	6.12		6.14			6.9	6.12		6.14			6.9	6.12		6.14		
	m=1						m=2						m=3					
	Inv.	Inv.	Tec.	Inv.	Tec.	Int.	Inv.	Inv.	Tec.	Inv.	Tec.	Int.	Inv.	Inv.	Tec.	Inv.	Tec.	Int.
88										+	++	+			+		+	
87			++		++		—	—	++	—	++	++			++		++	++
86	++	++	++	++	++				++		++				++	−	++	++
85			++		++	++			++	−	++	+	++	++	+		+	+
84			+		++	++	++	++		+								
83	++	++			+													
82			++		++						+							
81																		
80	—	—				—												

+, –: Significantly positive or negative at 10% level
++, —: Significantly positive or negative at 5% level
☐: The model is not significant at 10% level
▰: No relevant period for the delay effects

Table 7. 4   The Significance of the Coefficients of the Models in a Single Year's Investment with One to Three Years' Time Lag (m = 1, 2, 3) in the 1980s

Table 7.4 reports the significance of the coefficients of the three step regression models of the lagged effects of investment and the use of technology on RoS for each year. The values of the coefficients of the variables in the models are reported in appendix 10. The adverse impact of investment on the same year's profitability noted is almost entirely absent in the lagged models. This is consistent with the notion that the cost of change is the greatest in the year of investment. Subsequently, it might be expected that the investment by itself might show a net benefit, but model 6.9 with lagged investment demonstrates this only erratically - just four of the ten years show this pattern, and these with lags varying from 1 to 3 years. Model 6.14 demonstrates little more than chance although the pattern of interaction offsetting investment effects described above is evident in eight cases. However, whether the hypothesis on interaction effect is supported or not is again decided much more by the increase of adjusted R^2 rather than just considering the significance of the regression coefficient related to the interaction term.

RoS	Model								
	6.12	6.14	Change by Int.	6.12	6.14	Change by Int.	6.12	6.14	Change by Int.
	m=1			m=2			m=3		
	$A\text{-}R^2$	$A\text{-}R^2$	$\varDelta A\text{-}R^2$	$A\text{-}R^2$	$A\text{-}R^2$	$\varDelta A\text{-}R^2$	$A\text{-}R^2$	$A\text{-}R^2$	$\varDelta A\text{-}R^2$
88	0.002	-0.005	-0.007	0.010	0.047	0.037	0.025	0.034	0.009
87	0.034	0.030	-0.004	0.137	0.154	0.017	0.062	0.141	0.079
86	0.150	0.144	-0.006	0.071	0.068	-0.003	0.068	0.095	0.027
85	0.063	0.087	0.024	0.041	0.055	0.014	0.087	0.160	0.073
84	0.008	0.065	0.057	0.080	0.085	0.005	-0.013	-0.022	-0.009
83	0.089	0.106	0.017	-0.007	-0.012	-0.005	-0.007	0.010	0.003
82	0.034	0.025	-0.009	0.021	0.010	-0.011	-0.005	0.005	0.010
81	0.001	-0.012	-0.013	-0.003	0.012	0.015			
80	0.194	0.260	0.066						

⬜ : The model is not significant at 10% level

⬛ : No relevant period for the delay effects

Table 7. 5   Adjusted R^2 and their Changes in the Lag Models, m = 1, 2, 3, in the 1980s

Table 7.5 reports adjusted R^2 of the models with and without the interaction term involved and the increment of adjusted R^2 caused by adding a multiplicative interaction term. There were only four increases of adjusted R^2 in the one year lagged model, compared with five decreases. There are five increases and three decreases of adjusted R^2 in the two years lagged models. However, there is strong consistent evidence on increase of adjusted R^2 in the three years lagged models (with only one decrease in the seven cases).

Therefore, the multiplicative interaction hypothesis between lagged investment and the use of technology on manufacturing performance is varied between the cases. It only can be said that the interaction model specification is working for the three years lagged model but not for the one and two years lagged models and the interaction effect of lagged investment and technology usage depends on the years of lagged investment.

The models have also been run for four to six lagged years of investment. The significance of coefficients of the models with four to six lagged years is reported in appendix 11. The pattern of significant results in four lagged years is very

similar to the ones in three lagged years. However, there are less significant coefficients in five and six lagged years models. The models from RoS 83 to 85 with more than three years lagged investment turned out to be not significant at all. Therefore it can be concluded that the investment in a single year with more than three years' delay did not show much influence on manufacturing performance increased by RoS and these results are not reported in the main text.

7.2.2   Effect of Investment in a Single Year and Technology Usage and Their Interaction on Performance in the Early 1990s

The characteristics (mean, minimum, median, maximum, standard deviation and sample size) of the sample for this period have been given for several representative variables in appendix 12. Two are performance variables, profitability (RoS%) and efficiency (TFP). Two are practice variables, investment% and technology index. Investment and RoS are scaled using their percentage values for the consistency of calculation with the other variables.

The correlation coefficient matrices between investment, technology usage index and the three performance measures are calculated for the period from 1989 to 1995 and are given in table 7.6.

r	RoS89	RoS90	RoS91	RoS92	RoS93	RoS94	RoS95
Tech.	**-0.396***	-0.312	0.093	-0.006	-0.067	0.036	-0.019
Inv89	0.119	0.041	-0.224	**-0.350***	-0.009	-0.015	0.123
Inv90		-0.297	0.003	**-0.363***	**-0.419***	-0.116	-0.208
Inv91			-0.258	-0.272	-0.198	-0.159	-0.279
Inv92				-0.146	-0.120	0.075	-0.096
Inv93					-0.089	0.098	0.012
Inv94						-0.053	0.062
Inv95							-0.014

r	TFP89	TFP90	TFP91	TFP92	TFP93	TFP94	TFP95
Tech.	-0.096	**-0.508***	-0.045	0.108	0.074	-0.011	0.193
Inv89	-0.247	**-0.388***	**-0.462***	**-0.521***	**-0.516***	-0.315	-0.150
Inv90		**-0.363***	**-0.406***	**-0.365***	**-0.341***	**-0.395***	-0.271
Inv91			**-0.615***	**-0.487***	**-0.478***	**-0.432***	**-0.424***
Inv92				**-0.348***	**-0.311***	-0.163	-0.050
Inv93					**-0.303***	-0.234	-0.079
Inv94						0.002	-0.069
Inv95							-0.085

r	RoA89	RoA90	RoA91	RoA92	RoA93	RoA94	RoA95
Tech.	-0.294	-0.286	0.154	0.131	0.124	0.130	0.129
Inv89	-0.026	-0.029	-0.145	-0.094	**-0.411***	-0.092	0.152
Inv90		-0.071	0.056	-0.069	**-0.359***	-0.112	0.014
Inv91			-0.265	0.040	**-0.406***	-0.294	-0.331
Inv92				0.082	0.074	0.086	0.087
Inv93					0.014	0.026	0.028
Inv94						-0.023	-0.019
Inv95							0.146

Bold number: the significant correlation coefficients at the level less than 10%.

Table 7. 6   Correlation Matrices of Investment, Technology and RoS, TFP and RoA for the Period from 1989 to 1995

From table 7.6, one can notice that only the correlation coefficients with TFP show relatively consistent significant results but not the ones with RoA and RoS in the early 1990s. The reasons are shared with the one mentioned in section 7.2.1 followed table 7.1. During this period, the lost in value added in this period was more significant than investment expenses and TFP had been negatively affected. Profit before tax was not significant compared with sales level and resulted in non-significant coefficients related to ROS for most of the cases. Therefore, the investigation for the relationship between investment, the use of technology, their

interaction and manufacturing performance is only carried out for TFP for this period.

TFP	Model						
	6.9	6.11	6.12		6.14		
	Inv.	Tec.	Inv.	Tec.	Inv.	Tec.	Int.
93	–		–				
92	– –		– –				
91	– –		– –		– –		
90	–	– –	–	– –	– –		

'–' or '——': Significant negative results of the coefficients at 10% or 5% level, resp.

Table 7. 7   The Significance of the Coefficients of the Models in a Single Year Investment without Time Lag (m = 0) in the Early 1990s

Table 7.7 reports the significance of the coefficients of the three-step regression models without lag effects considered (m = 0). The values of the coefficients of the variables are given in appendix 13. The models of 1989, 1994 and 1995 are not significant and so the results are not presented here. The data of 1996 has not been included in the estimation because the sample size is too small. All the significant coefficients of investment in model 6.9, which occurred in more than half of this period, are negative. This suggests that investment in this period correlated with reduced efficiency performance of companies in the same year. Because TFP is defined as value added divided by employment and capital costs, there is a general tendency for the ratio to be affected adversely by increased investment if value added earned in that year can not outweigh the cost of investment. To achieve a positive contribution, increase in value added or reduction in employment costs would have to consistently and significantly outweigh incremental capital costs.

As far as technology usage is concerned, model 6.11 did not return positive coefficients of technology usage on the efficiency of the companies in this period. There is one year showed a significant negative effect and no years showed significantly positive effects. Technology usage in this period did not reveal significantly positive relationships to RoS either based on the correlation matrices on RoS (see table 7.6) with one negative effect only.

When investment and technology usage are studied together in model 6.12 and the interaction effect between them included in model 6.14, there are less significant estimated coefficients of the models. In order to decided which step's model has a most appropriate specification for the relationships during this period, the comparison between adjusted R^2 of the models is required.

TFP	Model				Change by Int.
	6.9	6.11	6.12	6.14	
93	**0.068**	-0.021	0.059	0.056	-0.003
92	0.095	-0.022	0.088	**0.121**	0.033
91	**0.357**	0.077	0.353	0.345	-0.008
90	0.097	0.213	**0.272**	0.261	-0.011

Bold number: the highest adjusted R^2 of the three model specifications

Table 7. 8   Adjusted R^2 of the Three Steps' Models in a Single Year's Investment without Time Lag (m = 0) in the Early 1990s

Table 7.8 reported adjusted R^2 of the models in the three steps. The bold number in each year is the highest adjusted R^2 for the models in that year. Unlike the finding in the 1980s, it has not showed a steady pattern during this period. Model 6.9 is the best for two cases and one case each for model 6.12 and 6.14. Therefore, a general statement for the most appropriate model specification can not be made for this period. It depends very much on the year investigated.

In order to examine the delay effects of investment in a single year on TFP in the early 1990s, all possible delayed years have been run in the models according to the availability of the database. For instance, investment in 1989 may have delay effects on TFP from 1990 to 1995 and investment in 1992 may have delay effects on TFP from 1993 to 1995. The following table reports the significant results for all delay effects of investment in a single year and adjusted R^2 for the significant models in this period.

TFP	Model 6.9		Model 6.12			Model 6.14				Change
	Inv.	A-R^2	Inv.	Tec.	A-R^2	Inv.	Tec.	Int.	A-R^2	by Int.
Investment 89										
93	– –	0.238	– –		**0.271**	– –			0.254	-0.017
92	– –	0.243	– –		**0.253**	– –			0.222	-0.031
91	– –	0.183	– –	– –	**0.277**	– –	– –		0.252	-0.025
90	– –	0.118	– –	– –	**0.354**	– –	– –		0.346	-0.008
Investment 90										
94	– –	0.123	–		**0.176**				0.155	-0.021
93	– –	0.081								
92	– –	0.098								
91	– –	0.131	–		0.179		–		**0.205**	0.026
Investment 91										
95	– –	**0.149**	– –		0.119					
94	– –	**0.158**			0.077				0.137	0.060
93	– –	**0.201**	– –		0.177	–			0.149	0.028
92	– –	**0.210**	– –		0.183	– –			0.171	0.012
Investment 92										
93	–	0.075							0.102	

'–' or '––': Significantly negative results of the coefficients at 10% or 5% level, resp.
Bold number: the highest adjusted R^2 in the three model specifications

Table 7. 9   Significant Results of Lag Effect of Investment in a Single Year, Technology Usage and their Interaction on TFP in the Early 1990s

Table 7.9 reports the significant results and the adjusted R^2 of the lag models on TFP. The values of the coefficients of the variables in these models are reported in appendix 14. The results of the models are not significant when investment of 93 or 94 is employed. Also, the models are not significant when investment 89 with TFP 94 or 95, investment 90 and TFP 95 and investment 92 and TFP 94 or 95 were combined together. Therefore they are not presented in table 7.9. In the 1980s, we saw delayed positive effects of investment, but they were not appearing in the early 1990s. Indeed, any significant effects are consistently negative, especially for 89, 90 and 91 investment. It may suggest that the investment during this period was not well managed or was invested in things which were not crucial to the efficiency of a business. It may simply reflect a prevailing attitude that to sweat the assets and concentrate on HRM centred improvements, thus avoiding capital investment, was more effective than increased capital investment. It also

may reflect methodological issues since a relatively coarse data capture instrument was employed compared to the one in the 1980s. A more reasonable and confident interpretation cannot be provided without further research into the detail of which asset categories constitute the majority of the investment. However, it can be said that the negative effects were not becoming weaker in later years after investment occurred in the early 1990s.

The results on adjusted R^2 reported in table 7.9 support that the interaction models are general better specified when investment was employed in 1991. There are three significant models of the four related to delayed effects of investment 91, which are all better specified in the model with an interaction term. However, it did not happen for the other years' investment in the lagged models in this period. Actually, the course is reversed in 1989's investment delay effect models. In other years' investment, it did not show a consistent pattern and we can not draw any general conclusion about the most appropriate models for the relationships between investment in a single year with time lag and technology usage on efficiency manufacturing performance in the early 1990s.

7.2.3   Effect of Cumulative Investment and Technology Usage and Their Interaction on Performance in the 1980s

It has been discovered that there are no promising results on the effects of investment in a single year on manufacturing performance improvement in previous sections in this chapter. Following the literature suggestion, the effects of cumulative investment on manufacturing performance are examined and the results are reported in this section. Whether a planned long-term investment brings benefits to companies' performance improvement is answered for the 1980s. Again, RoS is used as the performance measure for this period.

The cumulative investment by itself from two to seven years has been regressed on the manufacturing performance RoS using model 6.10. The results on the significance of cumulative investment from two to seven years are given in appendix 15. The percentage significant positive effects of the cumulative

investment on RoS is increasing with the number of the cumulated years and reaches 93% at six years' cumulated investment (figure 7.1).

sig. pos. %
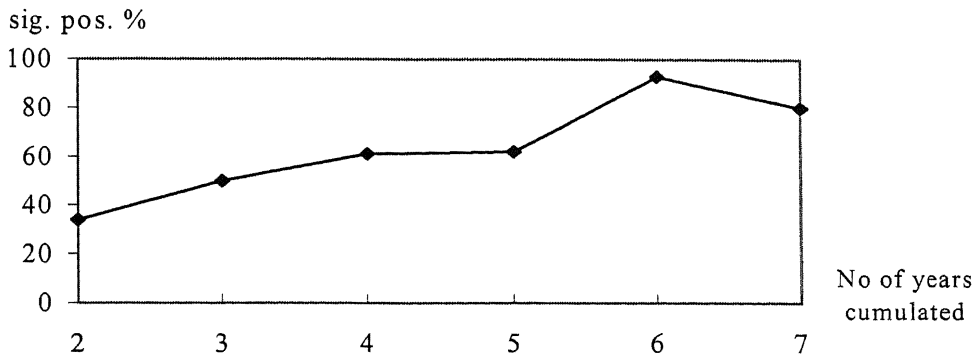
Figure 7. 1   Percentage Significant Positive Effect of Cumulative Investment in Different Cumulated Number of Years

It can be seen that the pattern of cumulative investment is a very much more reliable indicator of performance than the investment in any one single past year. There are suggestions that the investment a company has made in the previous six year matters in determining performance, but thereafter the effectiveness of past investment may diminish.

Therefore, six years' cumulative investment is used to further study the relationships between cumulative investment, technology usage and manufacturing performance. Because of the importance of avoiding discontinuities in company history, the actual sizes of the samples range from 19 to 92 for six years cumulative investment, depending on which years are investigated.

RoS	Model									Increment by Int.
	6.10		6.13			6.15				
	Inv79-84	A-R^2	Inv79-84	Tech.	A-R^2	Inv79-84	Tech.	Int.	A-R^2	ΔA-R^2
84	+	**0.033**	+		0.022				0.024	+0.002
85		0.023			0.017				**0.034**	+0.017
86	++	0.046	+		0.047				**0.060**	+0.013
87	+	0.049			0.046				**0.080**	+0.034
88	+	**0.118**			0.102				0.042	
	Inv80-85	A-R^2	Inv80-85	Tech.	A-R^2	Inv80-85	Tech.	Int.	A-R^2	ΔA-R^2
85	++	0.048	++		0.047				**0.058**	+0.011
86	++	**0.080**	++		0.077	++			0.076	
87	++	0.064	++		0.053				**0.081**	+0.028
88	++	**0.186**	++		0.165	+			0.132	
	Inv81-86	A-R^2	Inv81-86	Tech.	A-R^2	Inv81-86	Tech.	Int.	A-R^2	ΔA-R^2
86	++	0.068	++		0.072	+			**0.079**	+0.005
87	++	0.082	++		0.077	+		++	**0.131**	+0.058
88	++	**0.138**	++		0.150	+			0.114	
	Inv82-87	A-R^2	Inv82-87	Tech.	A-R^2	Inv82-87	Tech.	Int.	A-R^2	ΔA-R^2
87	+	0.037	+		0.041				**0.056**	+0.015
88	++	0.085	+		0.086				**0.095**	+0.009
	Inv83-88	A-R^2	Inv83-88	Tech.	A-R^2	Inv83-88	Tech.	Int.	A-R^2	ΔA-R^2
88	++	0.093	++		**0.094**	++			0.083	

'+' or '++': significantly positive results of the coefficients at 10% and 5% level, resp.
Bold number: the highest adjusted R^2 in the three model specifications

Table 7. 10 The Significant Results and Adjusted R^2 of the Models of the Relationship between Cumulative Investment (Six Years), the Use of Technology, their Interaction and RoS.

Table 7.10 reports the significance of the coefficients and the adjusted R^2 of the model 6.10, 6.13 and 6.15 employing six years' cumulative investment. The values of the coefficients of variables of these models are reported in appendix 16. The first column of table 7.10 reports the significance of the coefficients of six years' cumulative investment on corresponding years' RoS. They are all significantly positive at 5% or 10% level except for cumulative investment from 1979 to 1984 against manufacturing performance in 1985 (Ro85), for which the significant level is 10.7%. This supports the hypothesis that a planned long-term investment (especially over six years' period) did contribute to manufacturing performance improvement measured by RoS in the 1980s.

The remaining models (6.13 and 6.15) seek to explore the interaction effect alongside six years' cumulative investment. Comparing adjusted R^2 of model 6.13 with the ones of model 6.15, there are 10 of 15 cases with higher adjusted R^2 by adding an interaction term between six years' investment and technology usage. When comparing adjusted R^2 among the three models, there are still 9 of 15 cases with the highest adjusted R^2 associated with the interaction model 6.15. It implies that the model with interaction term is the best model specification in general during this period.

However, most estimates of the coefficients in the model 6.13 and 6.15 are not significant. The data continuity necessary for the estimation results has reduced the sample size of each group to between 19 and 92 cases. These sample sizes are sufficient to show the positive effects of cumulative investment on performance. However, the results of the significantly positive effects of technology usage on manufacturing performance RoS using the full samples have been lost when the smaller samples are employed. The results on significance of technology usage on performance between the full samples and the smaller samples for consistent with six years cumulative investment have been compared and given in appendix 17. It can be easily noticed that the significant results of technology usage with the full samples did not show using the smaller samples drawn from the full samples, except for one with largest sample size (92) among all the smaller samples. Therefore, the effect of technology usage on performance fails to be demonstrated with the smaller samples. This may be the reason for the non-significant estimates of the coefficients in model 6.13 and 6.15. The importance of large cross-sectional samples to this research methodology, therefore, is emphasised.

7.2.4   Effect of Cumulative Investment and Technology Usage and Their Interaction on Performance in the Early 1990s

The significant results of cumulative investment from two to six years on TFP have been reported in appendix 18. The significant negative results turned up in most cases and no single positive sign occurred during this period. Therefore there is no choice for a certain number years of investment, which might be used for

further investigation on an interaction model. Hence, this process was not pursued.

7.2.5   Comparison between the Findings in the 1980s and the Early 1990s

Three performance measures have been considered for the investigation of the relationship between investment, the use of technology and manufacturing performance. However, only RoS has been used to run the interaction models in the 1980s and TFP has been used to run the interaction models in the early 1990s.

This makes the comparison of the findings related to the interaction effect in the two periods difficult. Also, the sample sizes of the two periods are very different (175 v 45) due to the exits of the companies in the original database during the period from 1989 to 1996 and the response rate of the companies to the questionnaires on technology usage for this period. Before any comparison is carried out, the extent to which the smaller samples represents the original samples has to be tested using the database in the 1980s, which includes the data of both survival and non-survival companies' information. The comparison results on RoS and TFP using the two different samples are given in appendix 19.

The results by inspection show that the sub-set is not representative of the full set on RoS. However, it takes a quite similar shape on TFP, especially in step 1. The coefficients in the other steps follow the same signs as the ones within the original sample even though they occurred in different years. Therefore, it can be said that the behaviour of the sub-set reflects that of the full set for TFP only.

Taking account of the correlation matrices of RoS and TFP generated for the two periods for the three performance measures, a basic comparison between the findings in the 1980s and the early 1990s is possible. In general, investment in a single year had significantly negative effects on the same year's manufacturing performance measured by RoS in the 1980s but this did not persist into the early 1990s. However, there were no significantly positive effects of investment in a single year on the same year's RoS either in the early 1990s. The negative effect of investment in a single year on RoS did disappear in the later years in the 1980s.

In the early 1990s, there are a couple of negative effects of investment in a single year with time lag on RoS, which occurred totally by chance. However, the significant negative effects of investment in a single year on the same year's TFP with half of the cases in the 1980s became stronger in the early 1990s. Furthermore, the significantly negative effects on TFP did disappear in the later years in the 1980s but not in the early 1990s. The significantly consistent positive effects of cumulative investment, especially in six years, in the 1980s on RoS did not occur on the TFP in the early 1990s. In the early 1990s, negative effects of cumulative investment were observed but became weaker as the number of the years of investment cumulated.

As far as technology usage is concerned, the positive effects of technology usage on manufacturing performance in profitability in the 1980s did not show its benefits on manufacturing efficiency in the early 1990s. It may be because technology usage is no long an essential factor for performance improvement in the 1990s due to the human factors becoming more and more important for the companies performance improvements. It may be also a reason that there is smaller number of the companies available in the early 1990's database.

The interaction effect of investment and the use of technology enhanced RoS when investment was employed in a single year without time lag and in three years time lag in the 1980s. But it is untenable in the early 1990s except for a few cases in 1991's investment which support the interaction effects. In the 1980s, the interaction effect of cumulative investment, especially in six years, were also supported by most of the cases. Except for the interpretations of these results through sections 7.2.1 to 7.2.4, the significance of these results is discussed in section 8.2.2.

7.2.6   Findings on Multiplicative Interaction Model for Relationship Studies

In this section, the findings on interaction models are generalised. In the previous section, multiplicative interaction models have been used to model the relationships between investment, technology usage and a single manufacturing performance measure. The interaction models are not always the best model

specification for the cases studied. However, the value of interaction models for modelling the relationships can not be denied simply because in some cases interaction effects between investment and technology usage cannot be demonstrated.

It can therefore be said that the multiplicative interaction model is a useful tool for modelling relationships. Multiplicative interaction model provides another research tool for researchers who are interested in modelling the relationships in which one of the factors in causes may have different effects on the outcomes depending on different levels of the other factor(s).

7.3   Part 2 – Findings on Two Performance Variables Model

In manufacturing performance measurement research and practice, a measurement system including more than one performance measure is getting more and more important. It is because that this kind of system can measure performance from more than one dimension at once and provide more information on manufacturing performance improvement. Due to above reasons mentioned, modelling more than one dependent variable becomes more and more meaningful, especially when the performance measures included in the system are joint products by the factors considered.

In this section, the results of the relationships between investment, the use of technology on two dimension performance measures, RoS and Growth, using the multiple outputs model (model 6. 22) developed in chapter 6, are presented.

The multiple outputs model is run only using the data in the 1980s due to the inconsistent results discovered for the early 1990s for the single performance measure models. The investment in the multiple-outputs model has employed six years' cumulative investment due to the most consistent positive effects of six years' cumulative investment on RoS discovered in the single performance measure models in the 1980s.

7.3.1   Effects of Cumulative Investment and Technology Usage and Their Interaction on Two Dimensional Performance Variables in the 1980s

The database of this period covers the years from 1979 to 1988, however, the actual range which can be used for the multiple-outputs model to ensure all relevant data available is from 1980 onwards because the calculation of growth takes the first year (1979) as a base year. Therefore, the model has been run for investment cumulated from 80-85 through to 83-88 with the performance variable of the period end or a later year. The results are reported in table 7.11.

In order to determine which one of the two output coefficients should be set to unity, the model has been run for either $\beta_1 = 1$ or $\beta_2 = 1$. When β_2 is set to unity, for some years, the estimates of β_1 are enormous and the corresponding models are not convergent in these cases. Therefore, the coefficient β_1 which is related to RoS has been set to 1. The estimated coefficients for β_2 can be used to determine whether return and growth are two joint products by cumulative investment and technology usage.

	Const.	α_1	α_2	α_3	β_2	R^2**	N***	F_{static}
Inv.80-5, P85*	9.453	0.087	0.047	0.002	0.215	0.128	83	12.28
Inv.80-5, P86	7.224	0.054	0.039	0.001	0.044	0.126	81	11.67
Inv.80-5, P87	7.264	0.039	0.016	0.002	0	0.164	51	10.03
Inv.80-5, P88	7.679	0.084	0.088	0.001	0	0.236	21	6.51
Inv.81-6, P86	6.925	0.039	0.043	0.001	0.008	0.128	90	13.22
Inv.81-6, P87	8.167	0.054	0.018	0.002	0.062	0.204	58	14.93
Inv.81-6, P88	7.683	0.090	0.134	0.001	0	0.247	25	8.22
Inv.82-7, P87	6.660	0.023	0.055	0.003	0	0.135	71	11.03
Inv.82-7, P88	6.975	0.042	0.105	0.004	0	0.220	35	9.89
Inv.83-8, P88	9.510	0.119	0.052	0.001	0.149	0.177	40	8.62

*.   Cumulative investment from 1980 to 85 and performance variable in 1985. The same notation follows in this column.
**. R^2 generated from maximised correlation for the whole model.
***. Sample size.

Table 7. 11   The Results of the Multiple-Outputs Model with $\beta_1 = 1$.

Table 7.11 reports the estimated coefficients of the multiple-outputs model using maximum correlation method when β_1 is set to 1, along with the maximised R^2 of

the model in each combination of the cumulative investment and RoS and F statistic for the corresponding R^2.

From table 7.11, one can see β_2, which is related to value added growth, is null in half of the cases studied. These cases with null β_2 are the same as those which are not convergent when β_2 is set to 1.

This suggests that cumulative investment and the use of technology do not always contribute to the both dimensions of performance improvement - return and growth. However, it does not imply that they are not joint products of cumulative investment and the use of technology because there are still five out of ten cases supporting the joint products hypotheses, including the majority of the immediate year or years' performance outcomes after cumulative investment was made.

For the models supporting the joint products' hypothesis, the values of β_2 are always much less than 1. After converting β_2 to 1 for these models, one unit of β_2 which represents value added growth is actually associated with higher values of coefficients of cumulative investment, technology usage and their interaction term (α_1, α_2, and α_3) than the ones related to one unit of RoS.

Therefore, the things established are:

1. cumulative investment and the use of technology consistently contribute to the improvement of profitability measured by RoS during the years investigated, which is consistent with the results discovered in the first stage, and

2. the sensitivity of change in cumulative investment and/or the use of technology is stronger on the improvement of value added growth than on the improvement of RoS for the years when the joint products of RoS and value added growth are supported.

The results related to the coefficients in the right side of the model (a_1, a_2 and a_3) suggest that positive effects of cumulative investment, the use of technology and their multiplicative interaction on the performance measured by either RoS or value added growth or both occurred consistently in the past.

All maximised correlations have been tested for their significance using F statistics and all of them are significant at 1% level. This means that all the models are highly acceptable according to R^2 of the model. The model has an accepted goodness of fit and it is specified well enough to be adopted.

When β_2 is equal to 0, the explanation of the coefficients for the model is the same as the interaction model with only one dependent variable. Without centralisation, the coefficient of each independent variable involved in the interaction represents the unit change of that variable when the other independent variable is equal to 0. However, when the centralisation is used to reduce multicollinearity, the coefficient of each independent variable involved in the interaction represents the unit change of that variable when the other independent variable is equal to its mean. Using the relationship between cumulative investment from 80 to 85, the use of technology, their multiplicative interaction and performance in 1987 with $\beta_2 = 0$ (the third row in table 7.11) as an example, an increment of one unit of cumulative investment would result in 0.04 unit of increase in RoS when the technology is at its average level. If increasing one unit of cumulative investment and one unit of technology index from their average levels, RoS could improve not just 0.056(=0.040+0.016) but 0.058 (=0.040+0.016+0.002) units. If the increases are not from their average levels, the improvements have to be adjusted by adding a conditional increase $0.002(x_1 + x_2)$ (x_1, x_2 are centralised). The conditional increase depends on the levels in which certain values of RoS and technology are taken because the effect of an interacting independent variable on dependent variable is influenced by the other interacting independent variable's level in an interaction model.

When the model shows that the two dimensional outputs are joint products by cumulative investment and the use of technology ($\beta_2 \neq 0$), the explanation for the model is given by the following example. Using the first case (the first row in table 7.11), increasing one unit of cumulative investment could cause up to 0.087 unit of increase in RoS or up to 0.405 (=0.087/0.215) unit improvement in growth or an intermediate contribution to both, when the technology is at its average level. If not, the improvements have to be adjusted by adding a conditional increase $0.002x_2$ on RoS (because $\beta_1 = 1$) or a conditional improvement $0.002x_2/0.215$ on growth (converting β_2 into 1 from 0.215), or an intermediate contribution to both (x_1 and x_2 are centralised). The reason to divide the coefficient of cumulative investment by the coefficient of value added growth is to obtain the value related to cumulative investment corresponding to one unit of value added growth. When increasing one unit of cumulative investment and one unit of technology usage from their average levels at the same time, the improvement for RoS could be increased up to 0.136 (=0.087+0.047+0.002) unit or for growth up to 0.633 (=0.136/0.215) unit. If not, the improvements have to be adjusted by adding a conditional increase 0.002 (x_1+x_2) in RoS or a conditional increase $0.002(x_1+x_2)$ in growth (x_1, x_2 are centralised). All the units have to be related to the scales of the measures used, as defined earlier. An investigation of the split between contribution to RoS and to growth is a recommendation for further study due to no suitable methodology for further investigation being available for this issue at this time.

7.3.2   Multiple Outputs Model for Relationship Studies

The results support the hypothesis that the multiple-outputs model is successful in modelling the relationships between cumulative investment, the use of technology and manufacturing two dimensions of performance. The same principle of the modelling and estimating method, i.e. the maximum correlation method, can also be applied to any multiple outputs model with more than two outputs to represent more than two dimensions of performance. The multiple-outputs model provides another useful tool to model relationships with more than one outcome, especially where the outcomes may be joint products produced by the inputs. The multiple-

outputs model generates individual reference to each outcome rather than a single coefficient of the index composing all the dimensions.

	Model 6.15					Model 6.22				
		Inv.	Tech.	Int.			Inv.	Tech.	Int.	
	$Const.$	β_1	β_2	β_3	R^2	$Const.$	α_1	α_2	α_3	R^2
Inv.80-5, P85	6.574	0.049	0.023	0.001	0.092	9.453	0.087	0.047	0.002	0.128
Inv.80-5, P86	6.903	0.064	0.021	0.001	0.110	7.224	0.054	0.039	0.001	0.126
Inv.80-5, P87	7.494	0.049	0.013	0.002	0.134	7.264	0.040	0.016	0.002	0.164
Inv.80-5, P88	7.364	0.139	0.051	-0.001	0.245	7.679	0.087	0.088	0.001	0.236
Inv.81-6, P86	7.077	0.050	0.027	0.001	0.109	6.925	0.039	0.043	0.001	0.128
Inv.81-6, P87	7.850	0.050	0.014	0.002	0.175	8.167	0.055	0.018	0.002	0.204
Inv.81-6, P88	7.968	0.108	0.078	0.000	0.213	7.683	0.094	0.139	0.001	0.247
Inv.82-7, P87	7.187	0.044	0.036	0.002	0.096	6.660	0.023	0.055	0.003	0.135
Inv.82-7, P88	7.621	0.075	0.051	0.002	0.171	6.975	0.042	0.105	0.004	0.220
Inv.83-8, P88	8.408	0.091	0.048	0.001	0.148	9.510	0.122	0.053	0.001	0.177

: Only RoS is supported as the product of cumulative investment and technology usage.

Table 7. 12 The Comparison of Model 6.15 and Model 6.22

The results on coefficients and R^2 of model 6.15 and model 6.22 are given in table 7.12 for the comparison purposes. In model 6.15, only RoS has been considered as the dependent variable, whilst in model 6.22 the RoS and value added growth have been treated as the dependent variables. The two models generate very similar results for coefficients of the independent variables. However, R^2 in model 6.22 is significantly higher than the one in model 6.15 for all the cases in which joint products hypotheses are supported, except for one case, which is investment from 80 to 85 and performance 88, R^2 is slightly higher in the multiple-outputs model than the one in the interaction model.

Therefore, the multiple outputs model can be a better specified model to describe the relationship especially to discover whether the outcomes are joint products produced by other factors investigated than two single dependent variable regression models.

7.4   Summary

In summary of this section, two types of models have been applied in the UK manufacturing database to discover the relationships between investment, the use

of technology and manufacturing performance in the past. Most of the works related to these findings have been published (Li and Hamblin, 1997, 1998a and 1998b).

The first type of model investigates the multiplicative interaction of investment, the use of technology and their effects on manufacturing performance either in profitability or efficiency. The two periods' data have been used, from 1979 to 1988 and from 1989 to 1995. In many aspects investigated, the results in these two periods are different, which may represent the changes between the 1980s and the early 1990s on the relationships between investment, the use of technology and manufacturing performance.

In detail, investment has been investigated in three forms. The three forms are investment in a single year without time lag, investment in a single year with time lag and cumulative investment. Investment in a single year without time lag contributed diversely to the same year's performance, measured by RoS in the 1980s and TFP in the early 1990s. However, significantly negative effects of investment in a single year disappeared as expected in the lagged models in the 1980s but not in the early1990s. The use of technology showed its benefits on performance improvement in the 1980s but not in the early 1990s. It may imply that there was an essential function of technology usage in its earlier employment time but its essential role has diminished whilst other factors may have an increased importance on manufacturing performance improvement in the technology mature era. The best form of investment was a planned long-term investment in the 1980s. It has been supported by the model results using cumulative investment. Six years' cumulated investment has the most consistent significant positive effects on manufacturing performance improvement in the 1980s. However, cumulative investment did not show the same positive impact on the performance improvement in the early 1990s. Again, performance variability must be dominated by factors other than cumulative investment and technology usage in the later period.

The second type of the model is the multiple-outputs model to investigate joint products of RoS and TFP by six years' cumulative investment and the use of technology employing the data of the 1980s. The results supported that six years' cumulative investment and technology usage with their interaction effect contribute to RoS all through the investigated years, which is consistent with the findings in the first type of the model. However, six years' cumulative investment and technology usage and their interaction effect only contribute to the immediate year or year two of company's growth based on value added. It is quite reasonable that company's growth can not be carried on without new investment and a higher quality of technology in use. Therefore, RoS and Growth are joint products by cumulative investment, technology usage and their interaction only for the immediate year or two after investment being invested. Within these years, the sensitivity of growth appeared stronger compared to the one of RoS based on their measurement scales used.

The multiplicative interaction model and the multiple-outputs model provide two additional choices for researchers who are interested in modelling the relationships. The possibility of applying these two types of models is shown in this research. A multiplicative interaction model can be extremely useful when one of the independent variables investigated depends on the level of the other independent variable(s). When joint products are investigated, a multiple-outputs model may provide a more appropriate model specification to describe a relationship between the factors.

Of course, the reality of manufacturing management is much complicated. No single model can be used to describe the relationship exactly and all we can do is to discover more choices to model the relationships as closely as possible with limited resources. Thus we endeavour to ensure that the findings discovered using the chosen model provide reliable information of the relationship in the past to possibly become a useful reference for future development.

Chapter 8   Discussions and Conclusions

8.1   Introduction

This research has focused on the methodology development of the quantitative evaluation of the manufacturing practice and performance relationships, especially on the relationship between investment, the use of technology and manufacturing performance.

Two types of econometric models have been developed in this research, which form two kinds of methodologies to benefit the modelling of manufacturing practice and performance relationship studies. The two types of models are the multiplicative interaction model and multiple-outputs model. Compiled with correspondent estimation methods for the models and the related essential approaches which are required during the modelling and estimating process, the two methodologies have been developed.

In the methodology involving the multiplicative interaction model, a centralisation approach has been introduced and employed to reduce the problems caused by the interaction term. Afterwards, an ordinary least square method has been used to obtain unbiased coefficients of the multiplicative interaction model. In the methodology involving the multiple-outputs model, the maximum correlation method has been introduced and applied in the multiple-outputs model to retain the estimations of the coefficients of the model and at the same time to satisfy the maximised correlation between a set of inputs and a set of outputs. In applying these two methodologies, the data has been treated as individual years rather than a panel. The main reason is that the variable-technology index is not coded in time series and therefore the database including this variable is not a panel after all. Besides, the panel data estimate is not suitable for the investment variable alone, partly because the hypotheses involve cumulative investment, which changed the database's panel format corresponding to performance variables and partly because the database is discontinuous or unbalanced during the period and across the companies. Otherwise, using panel data estimation to discover a set of

coefficients to represent the whole period would be worthwhile for practitioners and should be considered.

In this chapter, the conclusions are drawn mainly based on the findings discovered using the two developed methodologies and in line with the established aim and objectives of this research. Emphasis is also placed on the hypothesised relationships and developed methods as well. The discussions are provided in the light of the theoretical studies, reviewed in chapter 2, followed by the recommendations for further research at the end.

8.2   Results and Implications

The research aim (page 2) has been achieved by conducting step by step work to realise the six research objectives (page 3), which have been established in the introductory chapter. The first four objectives are related to the stage outcomes of the research process. The last two objectives are directly related to the research aim, which are on the developed methodologies and the tested hypotheses.

Therefore, in this section, the following three aspects are covered. These are the results generated during the research process, the results and the interpretations on the tested hypotheses, and the findings on the developed methodologies.

8.2.1   The Results Generated during the Research Process

The research has reviewed the operational management theory and economic factors, on which the manufacturing relationships are based. The review has generated three groups of economic factors, which may influence manufacturing practice and performance relationships, and three groups of operational practice factors, which have been viewed as good practices in the operational management theory. This achieves the first objective.

The three groups of economic factors are summarised in table 8.1:

The factors at industrial level	industrial characteristics and structure industry life cycles or business cycles technology changes and opportunities at the industrial level market structure economics of scale
The factors related to policies and essential economics	government policies manufacturing investment incentives exchange rates interest rates oil prices
The factors related to a nation's economic status	total investment economic or environmental stability inflation growth or recession

Table 8.1   Economic Factors, which may influence manufacturing practice and performance relationships

The review of the operational management theory generated three groups of practice factors (also see table 2.1), which are re-summarised in table 8.2:

Design related Factors	Investment in design R&D Cost-reduction in design Use of technology in design Quality management in design Interactive design Job-design-Human resource management
Planning and control related factors	Capacity management Inventory management Supply-chain management MRPI and MRPII JIT Quality planning and control
Improvement related factors	BPR Input-output analysis Flow charts Scatter diagrams Cause-effect diagrams

Table 8.2   Manufacturing Practice Factors in the Operational Management Theory

After reviewing these factors, the review of the published empirical studies in this area sheds a different light. Furthermore, the discovered relationships between practice and performance in manufacturing domain have further been clarified using the meta-analysis methodology. The meta-analysis methodology generates six good practices in general and three accepted effect sizes of the relationships, which complete the second objective.

These six good practices cover a wide range of aspects related to the manufacturing operational process as a whole. Based on the structure of the operational management, the six good practices are arranged into the following three groups:

(1) Design

Job-design:	*Human resource management*, such as human resource management related programmes,
R&D:	*Product development*, such as new product development activities including R&D,
Use of technology:	*flexible manufacturing system* (FMS)

(2) Planning and control

JIT related	*lean production,*
Quality	*quality management*

(3) Investment   *long-term investment*

The first two groups are directly related to the operational management functions (Slack et al, 1995, also see table 2.1 and table 8.2). In the operational management theory, these practices have been accepted generally as good practices that contribute to manufacturing performance improvement. Investment has been classified into a separate group and not been placed in the first one because investment here is not just for design investment alone, which has been described as the design function of the operational management (Slack et al, 1995). Investment here refers to long-term investment regarding the manufacturing organisation as a whole, which has been discussed in section 5.5.1.

Compared with the factors summarised in the operational management theory (table 8.2), the six good manufacturing practice factors studied in the empirical studies only cover part of them. There are always gaps between theories and practices. It has been discussed in chapter 2.2.3 that theory directs practice and the development of practice studied in empirical work can cumulate knowledge and eventually assist the establishment of theories. The gap in this area forms the fourth gap, which has been discussed in chapter 5 and is summarised later in this section.

The generated six good practices for manufacturing companies' performance improvement suggest that many aspects can be consequential for manufacturing companies' performance improvement. Neglecting any of them can influence the manufacturing performance improvements. A good staff team with quality training provided, an emphasis on new product development, along with effective planning and control, especially in quality and production, and a proper planned long-term investment will ensure higher opportunity for companies' performance improvements. These factors can be built into a balanced scorecard in the future to assist manufacturing companies' decisions in general.

The meta-analysis also discovered the activity of human resources management related programmes influenced 45 percent of the variability of performance improvements in quality, whilst new product development contributed 35 percent of the variability to manufacturing companies' growth in the past. It is reasonable that the human aspect is essential to achieve high quality performance and a company can not grow in the long-term without new products. Product or geographic diversification did not affect the improvement of manufacturing performance. There is not much relevant operational management theory related to diversification. However, there are two opinions towards diversification strategy in practice. One is focusing on few key products and markets which may allow a company to emphasise its strength and potential in order to be competitive. The other one is developing more products and more markets to

ensure the company's survival because there are still other products or markets if some products are unsuccessful or some markets have been lost. Actually, these two concerns in two different directions may balance out. This could be the reason that diversification was neutral towards manufacturing companies' performance improvement in the past. These three discovered effect sizes have no references in the theory. It has been discussed in chapter 2 that the conclusions at this detail are very difficult to reach at the firm level. Therefore there are no universally consistent remarks regarding these respects in the theory.

The quantitative methods which were employed in the past manufacturing practice and performance relationship studies have been reviewed and classified into correlation analysis and regression analysis which includes four sub-groups. This satisfies the third objective. The four summarised groups of regression analysis methods are multiple linear regression analysis, stepwise multiple regression analysis, multiple regression in interaction models and multiple regression in log transformation.

Based on the literature review of the theory and empirical work and the meta-analysis results, the gaps of the manufacturing practice and performance relationships are discovered and summarised into 36 relationships. The further investigation on the sizes of these relationships is worthwhile. Of these 36 relationships, 14 are related to economic factors and 5 are the operational management practices. The remaining 17 are generated from the meta-analysis. Of these 17 relationships, 7 relationships are identified with specified performance measures (table 8.3) and the rest of them are with a general performance variable (table 8.4) because there were not enough studies on any specific performance measure in these relationships studied in the past. It is infeasible to cover every single relationship for which there is no size conclusion. However, these 36 relationships are listed as the most relevant relationships for further investigation at this stage. This constitutes the results of the first part of objective 4.

Performance	Practice	Explanations
'Return'	NPD	The correlation coefficients reported for these relationships were diversified in individual studies. These studies were mostly set in different countries. The definitions of variables were not fully consistent through the studies. It was impossible to further classify these relationships due to the limited number of the studies. We conclude that the factor of country and the definitions of variables may be the reasons for non-convergent effect sizes reported.
	Hostility	
	Focus	
'Financial'	Age	
	Size	
Lab. Prody.	HRM	
'Non-fin.'	Action prog.	

Table 8. 3   The Relationships without Confirmed Effect Sizes-Gap Type 1

Table 8.3 reported seven relationships with non-convergent effect sizes reported in the literature. Three of them are related to 'Return', of which the practice factors are new product development, environment hostility and focus. The size of new product development and 'growth' has been confirmed, however the size of new product development and 'return' requires further testing. Besides, the size of the relationship of age/size of firm and financial performance require more work to reach a convergent conclusion. On the one hand, human resource management related programmes have been confirmed with 45% of variability related to quality improvement; on the other hand, the results on the size of human resource management related programmes on labour productivity were too diverse to reach a conclusion. Moreover, the size of implementing action programmes and non-financial performance measure has been studied in the past but the result on it has not been confirmed by the meta-analysis. These seven relationships were reported with mostly positive effect sizes in individual studies. But the combined results of their effect sizes on performance are unacceptable due to diverse outcomes through the studies.

Practice factors	Explanations
Quality management	These four practice factors have been confirmed as good practices but no studies have been discovered to have investigated their sizes on manufacturing performance. Therefore, further studies on their effect sizes are required.
Long-term investment	
FMS	
Lean production	
Use of technology	There are insufficient studies on the relationships between these factors and manufacturing performance to draw qualitative conclusions, let alone establish the sizes of these relationships. Therefore, the studies either on qualitative investigation or effect sizes of these relationships are needed.
Unionisation	
Strategic planning	
Cost reduction	
Export	
Market share	

Table 8. 4   The Practice Factors with their Effect Sizes on Performance required further Investigation-Gaps 2 and 3

Table 8.4 reports ten practice factors whose effect sizes on manufacturing performance require further investigation based on the meta-analysis results. There are two different reasons related to this issue, which are listed in the section of explanations in table 8.4.

In detail, these ten practices are separated in two groups. The first group covers four of the six good practices whose effect sizes have not been discovered. These four practice factors are quality management programmes, long-term investment, flexible manufacturing system and lean production. These four operational practices are supported by the operational management theory as good practices for performance improvement. Therefore, discovery of their effect sizes on manufacturing performance will be particularly useful and help establish complete information on these good practices.

In the second group, six factors are included. There are insufficient studies on these six factors to draw any conclusions on their relationships with manufacturing companies' performance. These six factors are the use of technology, unionisation, strategic planning, cost reduction, export and market share. In the theory, use of technology and cost reduction have been viewed as useful operational practices. But there are not enough empirical studies to test them in practice. Whether these practice factors are good for manufacturing and how much the variability of these practice factors is responsible for manufacturing companies performance improvement are worth investigating.

The difference between the good practice factors in the operational management theory and those studied in the empirical work generated part of gap 4. They are capacity management, inventory management, supply-chain management, MRPI and MRPII, and BPR. The 14 economic factors, summarised early on, constitute the rest of gap 4. The factors in this last gap are more general compared with the first three.

After the consideration of the availability of the UK cross sectional and time series database, the relationships between investment, the use of technology and manufacturing performance has been selected as the focus for this research. According to the review of the relationships between investment or technology and performance and the discussion of the influences of external factors on investment and technology usage, the seven hypotheses have been constructed. The establishment of these hypotheses has taken into account the different forms of investment and dimensions of performance measures. This completes the second part of objective 4.

The conclusions and discussions on the tested hypotheses and developed methodologies are given in the next two sections, to fulfil objectives 5 and 6. These are based on the modelling results with consideration of the operational management theory and the influences of external factors to firms and the UK economic background during this period.

8.2.2   Tested Hypotheses

The results of the modelling using the samples drawn from the UK manufacturing companies support the following findings related to each hypothesis.

Hypothesis 1: Investment in a single year has a negative effect on manufacturing companies' performance in that year but has a delayed positive effect on it in later years

This hypothesis actually consists of two parts. The first part is the negative relationship between single year's investment and the same year's performance. The second part is the positive relationship between single year's investment and the later years' performance.

The model results cannot reject the first part of this hypothesis at 5 % significant level and cannot accept the second part of this hypothesis at 10% significant level for most years investigated, except for a couple of exceptions (detail see chapter 7). In other words, investment in a single year had a negative relationship by itself with that year's RoS in the 1980s and TFP in the early 1990s, and had no positive effects on the late years' performance in general.

The negative relationship of the first part can be attributed to the launch expenses of investment. A recent study (Dasgupta, et al., 1999) using a cross sectional American manufacturing database discovers the negative effect of information technology investment on the same year's firm productivity and no time delay effect has been investigated in their study.

Investment theory suggests that it takes time for organisations to gain the benefits from an investment. A several years payback period is expected, especially for a long-term investment, let alone the investment has been planned for several years to be implemented for its completion. But gains in performance are expected during the payback period. However, the complete gains are assumed to be fulfilled over a number of years.

However, the benefit, which might be expected in later years, is not shown by the data. All that can be said about later years is that the negative first year relationship with RoS did not persist in the 1980s however it did with TFP in the early 1990s. The absence of apparent benefit might be attributed to a tendency for investment to be for other purposes, for example capacity expansion, rather than performance improvement. However, it may simply be due to a lack of effective investment over the study period. It may not be reasonable to judge the effect of investment on manufacturing performance improvement only based on a single year's investment. It is because a single year's investment is possibly only a small part of several investment projects covering several years. Therefore, it is unlikely the benefit will be seen in a year before the investment has been completed. This is the reason to propose hypothesis 2 dealing with cumulative investment.

Hypothesis 2: Cumulative investment has a positive effect on manufacturing companies' performance

The modelling results cannot reject this hypothesis using the 1980s' data but cannot accept the hypothesis using the 1990s' data at 5% significant level for most cases. Cumulative investment showed its consistent benefits on the manufacturing companies' improvement on RoS in the 1980s, especially six years' cumulated investment. It is expected that an investment increases either a company's capacity or contributes to its efficiency, which in turn possibly benefits its capacity at the end. It has been supported that a long-term planned investment contributed to manufacturing performance improvement in capacity to produce higher volume of return (profit before tax) for per unit sales in the 1980s. It took about six years to fulfil its potential. The reason why it took about six years may be because an average long-term planning normally has about five years' span and a project may be more likely to take average five years for its completion. About five years cumulative investment, in our case six years, may represent most investment project cycles. Moreover, environmental factors, such as government

investment policies and economic cycles, can also affect the span of an investment. These have been left for further research.

However, a long-term planned investment did not contribute to manufacturing companies' efficiency in the early 1990s. Actually, it showed a reversed impact on TFP in the early 1990s. It might be that management of investment was inefficient during this period or long-term investment was not actually planned and a set of individual investments on small projects occurred. In this period, there was a great deal of corporate restructuring under the guise of Business Process Reengineering, the impact of which may dwarf any investment-efficiency linkage. In addition, the recession of UK economics in the early 1990s, especially in 1992, might be the reason for inefficiency of investment or impossibility of long-term planned investment in this period. The study by Kitson and Michie (1996) confirmed that there had been under-investment in UK manufacturing, which was the key reason why British industry had been doing relatively poorly. The recession of the UK economy especially in 1992 has been supported by the data captured in this period. Section 5.4 provided the descriptive information on the relevant variables, of which RoA, RoS and profit before tax are all consistent with the recession in 1992 in the UK.

Because the detail on these investments could not be accessed as those in the 1980s, investigation on the inefficiency of cumulative investment in the early 1990s has to be left for further research when a database with detailed information on investment can be captured.

Hypothesis 3: The use of technology has a positive effect on manufacturing companies' performance

Again, this hypothesis cannot be rejected using the 1980s' data but cannot be accepted using the early 1990s' data at 5% significant level for most cases. Even though the significantly positive effect of technology usage on manufacturing performance measured by RoS did not occur in every single year investigated

during the 1980s, the trend is clear that the technology usage did enhance manufacturing performance improvement, especially in the late 1980s. The reason that the effect of technology usage in the late 1980s is more apparent than the one in the early 1980s may be because the technology indices used in the 1980s represent the late part of the period, when the data was captured, rather than the early part. The initial implementation of these technologies might not have been fully realised in the early 1980s. External factors such as technology opportunity in the nation and industry and stability of the economy also had influences on the chances of technology usage in individual companies during that period. For the same type of technology surveyed, the chance of using it was increasing whilst the years passed and the environment, in which it survived, should have been developed towards benign. It was obviously that there were better chances in the late 1980s than in the early 1980s for companies to have employed and implemented the technologies, which is supported by the data.

However, the positive trend of the technology usage did not affect efficiency measured by TFP in the early 1990s. It may imply that the strong positive impact of the use of technology on manufacturing performance improvement in the later 1980s is diminishing as the degree of maturity of the technology was increased by the number of the years in which the technology has been developed and used. It may show that new technologies are often more complex to maintain (Swanson, 1997). Attention should also be paid to leverage mature technologies to ensure the overall success for any industrial plant (Fitzgerald, 1997). Alternatively, it may be simply due to the data captured in the early 1990s being insufficiently refined to show its benefits. It also may be because the sectors diverged in behaviour, but there is insufficient data to demonstrate this. For example, the percentage of the clothing sector of the whole sample has dropped from 25% to 11% between the 1980s' database and the 1990s' database. It may also be because later generations of technology are more modest in impact than those in the later 1980s. However, further research is required to provide evidence on all these arguments.

It has been noted that employing advanced and new technologies is always essential for manufacturing companies' long term performance achievement and further strengthen the degree of survival and success ability in the future according to the theory related to technology (Harrison, 1990 and Zairi, 1992). In reality, the benefits brought by implementing or using a technology are affected by other factors, such as its excellence, the process by which it has been implemented and other uncontrollable external factors as well. Therefore employing certain technologies can be problematic.

Hypothesis 4: The multiplicative interaction between investment in a single year and the use of technology has positive effects on manufacturing companies' performance.

The modelling results cannot provide a single answer for this hypothesis, depending on the number of lagged years and the year or period investigated. The interaction effect between investment in a single year and technology usage is evident especially within the 1980s' data. However, this study on the details of nature of the interaction suggests that in practice over this period two effects were at work, one which provided a positive interaction in the year of investment, and one which provided a positive interaction in substantially later years, in this case three years after investment. These findings suggest a model advanced as figure 8.1, whereby there are significant early positive effects decaying rapidly and late positive effects building to become significant at around three years.
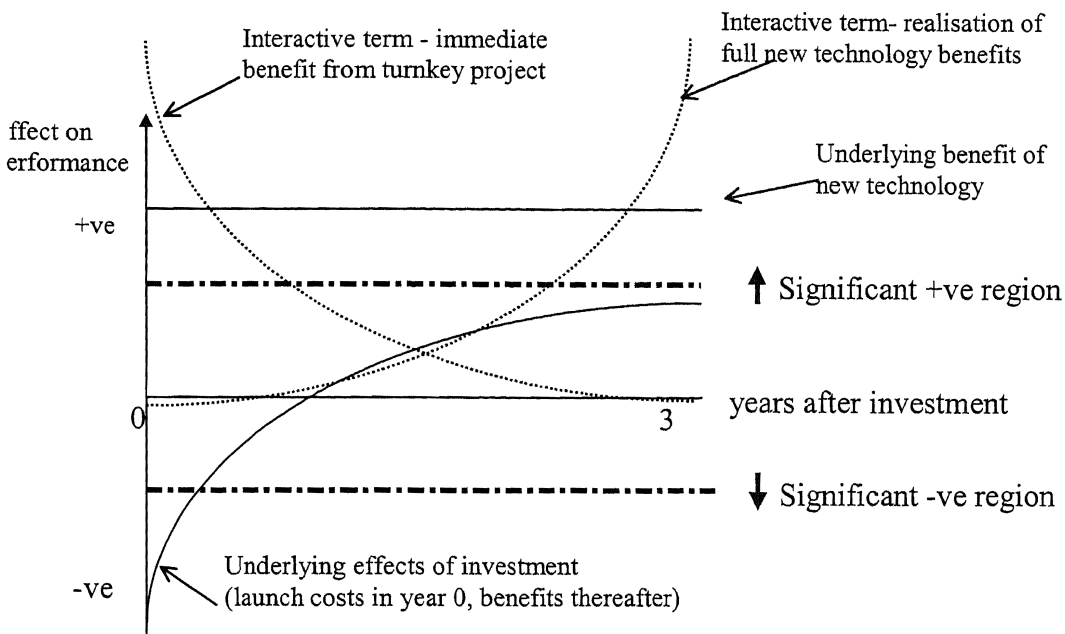
Figure 8. 1   Conceptual Model of Effects of Investment in a Single Year, Technology and Investment-Technology Interaction on Manufacturing Performance in the 1980s

Figure 8.1 provides a concept model on the findings related to the effects of investment in a single year and its interaction with technology usage on performance. The region between two bold broken lines indicates the relationships of non-significance. On the top of the non-significant region, positive relationships are represented; otherwise, negative relationships are represented. The solid curve line stands for investment behaviour on performance, which is negative at the year invested and non-significant relationship in later years. The dotted two lines represent interaction effects between investment and technology usage on performance, which support the two effects in the year invested and within three years' delay. The technology usage in this period was almost consistent with positive impacts on manufacturing performance, which is illustrated using a straight line.

The nature of the two interaction effects cannot be elicited from the data. However, the early effect might suggest that the high expense new technology

investments returned performance improvements quickly. It is possible that these were turnkey investments which were more likely to work first time than in-house lower cost investments which had to be debugged. The latter effect may provide evidence to support Primrose and Leonard (1986) who suggested that full implementation of new technology could take a significant time span and that benefits would still be increasing after a number of years. In addition, the cost on investment needs recovering. This is consistent with investment theory (Oldcorn and Parker, 1996).

However, the interaction effect between investment in a single year and technology usage is only supported when investment 91 was employed in lagged models during the period of the early 1990s. It occurred a little more than by chance. It is understood that the interaction effect between investment in a single year and technology usage is not supported because the effects of individual factors, either technology usage or single year's investment on performance, did not show significantly positive during this period. These two factors were not demonstrably beneficial for manufacturing companies' performance improvement in this period. It would be surprising if the interaction between them brought the benefits to manufacturing companies' performance. Therefore, the explanation for the interaction between these two factors not showing positive on performance is the same as the ones which have been mentioned for the individual factors of either investment in a single year or technology usage. The interaction effect between these two factors can be further investigated when a database can be collected including more details on investment and with a larger sample size which might show something related to technology usage in this period.

Hypothesis 5: The multiplicative interaction between cumulative investment and the use of technology has positive effect on manufacturing companies' performance.

This hypothesis has only been tested using the 1980s' database because of no single positive result for cumulative investment in the early 1990s. Therefore it is

not practicable to further investigate the interaction between cumulative investment and technology usage in the early 1990s.

The modelling results cannot reject the hypothesis at 5% significant level for most cases. The test of this hypothesis is based on six years' cumulative investment because six years' cumulative investment generates the highest percentage positive signs on the effects of cumulative investment on performance. For the data continuity necessary, the sample sizes for six years cumulative investment are reduced to between 19 and 92 cases, which are much smaller compared with the full sample size of 175. This leads to the loss of the significantly positive effects of the use of technology using the full sample. Therefore, interaction effects of six years' cumulated investment and the use of technology could not be fully explored until the larger data set required to estimate this complexity of model is available to at least ensure the positive effects of technology usage showing within the sample sizes used.

There are no relevant theory directly related to the interaction of cumulative investment and technology usage. However, due to the relationship between cumulative investment alone and manufacturing performance is supported by investment theory. The technology usage is studied as a joint factor to cumulative investment affecting on manufacturing performance. However, due to the database situation, the results can not be generalised to a consistent conclusion with evidence.

Hypothesis 6: Investment in a certain form has positive effect on manufacturing performance not only in profitability but also in growth

This hypothesis has been tested using the 1980s' data. The data of the early 1990s did not generate consistent results for the single performance variable models and therefore has not been used in the two performance variables model.

Hypothesis 2 is supported that cumulative investment is positively related to performance improvements in profitability (RoS) and it took about six years to reach its best effect. Therefore, six years cumulative investment is built in the multiple-outputs model to test the joint products of RoS and growth produced by six years' cumulative investment and technology usage.

The modelling results cannot reject the hypothesis at 5% significant level for half of the cases. For the other half, only RoS was working but not growth. The majority of the cases, which support the joint products hypothesis, are in the immediate year or two after the cumulative investment has been completed. It can be explained that when investment had been completed, its contribution to increase in capacity, which generated higher 'return' related to per unit sales, persisted into later years. This may suggest that economies of scale can be maintained after the improvement without further growth. However, growth is calculated by the difference of the values between the two successive time periods divided by the value in the earlier period. In our case, value added is used to calculate the growth, value added has to consistently increase to achieve the improvement of growth. Therefore, the contribution on 'growth' produced by the investment is limited to one or two years after the investment has been completed. Without further investment, the capacity may be still maintained but further growth is impossible. Hence, 'return' and 'growth' shared the resources of investment and technology usage only for a short period after investment occurred. Without further investment or improvement in status of technology usage, the shared resource situation of these two performance measures no longer existed.

For the joint products of 'return' and 'growth' of cumulative investment and technology usage, the sensitivity of improvements for both of the dimensions is different. The sensitivity of growth appeared stronger compared with the one of RoS based on their measurement scales used. It is possible that investment stimulated companies' growth intensively in the short period after the investment has been completed and soon the strength of growth is diminishing as the number

of years increase after the investment. However, the contribution of investment on RoS is a slow and steady process. When the capacity has been built up, perhaps the benefit in increased economies of scale can be enjoyed for a longer period.

Hypothesis 7: The use of technology acting as a joint factor with investment in a certain form has positive effect on manufacturing performance in both of the dimensions, profitability and growth

Again, only the data in the 1980s are applied for this hypothesis. In the multiple-outputs model, the interaction effect of the use of technology and investment has also been considered and built into the model. The modelling results cannot reject the hypothesis at 5% significant level. The use of technology was a joint factor, which interacted with cumulative investment to contribute to the improvement of manufacturing performance in both dimensions hypothesised for the immediate year or two after investment has been completed. Technology usage is measured using an index representing this period as a whole and no single year's data is available. Therefore, it can not be judged for individual years for technology usage and performance improvement. In general, the results of the modelling suggested that the two factors-cumulative investment and the use of technology were two important factors for performance improvement, especially for profitability measured by RoS and immediate year or two's growth after investment has been completed. Furthermore, studying the delayed effect of technology usage on performance is not feasible. The multiple outputs model results support that technology usage enhances the relationships between cumulative investment and manufacturing two dimensional performance- RoS for the period investigated and value added growth in the 1980s. It is consistent with the results discovered using the single performance model for technology usage in the 1980s.

It can be concluded that that technology usage helped investment to establish the profitability, however, increase in value-added growth is required by further investment in new or advanced technologies. The consistently upgrading the

technologies is necessary to ensure a further growth because any technology has its life cycle. The manufacturing companies are required to have a planned long term investment and employ advanced technologies in order to catch the steps of the changing world and to be competitive in the long run. This point is also supported by technology and investment in technology related theories (Oldcorn & Parker, 1996, and Zairi, 1992).

8.2.3   Values of Developed Methods for Relationship Studies

Conclusions are also drawn for methodology development. The research provides two developed methodologies involving two types of models, multiplicative interaction regression and multiple-outputs model.

The research amply demonstrates the value to researchers of considering the multiplicative interaction effect when building a model whenever a single or multiple outputs are considered. It is valuable to consider interaction effect in a model when the effect of one of the factors investigated as independent variables on the dependent variable(s) depends on the other independent variable or variables' level. This research also supports the desirability of the centralisation method used to reduce the problems caused by multicollinearity due to the interaction term during the multplicative modelling process.

This research also demonstrates the value of the multiple-outputs model of modelling multiple-dimensional dependent variables (multiple-outputs) relationships by constructing them into a single model, especially its applicability in a manufacturing relationship study. In addition, it has also been proved that maximum correlation is a useful method to estimate coefficients of a multiple-outputs regression model. This has important implication in being able to manipulate the contributions of practice factors to the Balanced Scorecard in the future.

However, there are still aspects related to the maximum correlation method which may need further exploration to improve validity of application of this method,

such as the conditions which may affect estimating results and the requirements of distribution of disturbance term.

8.3   Contribution to Current Knowledge

The literature review of this research has summarised the internal and external factors that are relevant to firm performance directly and indirectly at a theoretical level. This contributes to the knowledge related to the context on which factors influencing firm performance are based.

This research has reviewed and combined the academic studies on the relationships between manufacturing practice and performance from 1979 to 1995, when the literature review was conducted. The very recent studies (up to 1999) have also been searched and used in section 8.2 to make a connection (whether supportive or not) with the tested hypotheses. The results on the combination of the published research contribute to the knowledge on the clarification of the manufacturing practice and performance relationship studies and the relationships which are worth further investigation.

No prior application of the methodology using the interaction regression analysis has been discovered before on the relationship between investment, the use of technology and manufacturing performance, especially using a UK database. The methodology using the multiple-outputs model developed is entirely new for the manufacturing practice and performance relationship studies. These two methodologies developed and applied contribute to new knowledge in this area related to quantitative methods of studying relationships, especially for manufacturing practice and performance relationship studies.

The data captured for the early 1990s has brought the database up to date into the early 1990s. The descriptive analysis of the new data provides the information for this period from many perspectives. Particularly, the patterns of investment and investment percentage of value added are shown through the descriptive analysis. Until 1994, there were steady decreases for investment and investment of value added percentage since the very early 1990s. The profitability measured by profit

before tax, RoS and RoA and during the early 1990s followed the recession pattern, especially around 1992, but recovered afterwards. The trend of efficiency of TFP during this period was quite stable around an average of 2%, with a slight increase during the latter half of the period. Total turnover along with value added are also analysed for this period to increase these two measures measured in absolute values. The descriptive analysis confirms the recession in the early 1990s in the UK, especially around 1992.

The results of certain relationships studied using historical data can not necessarily guarantee correct decisions related to these relationships in the future. However, the intention of historical studies is to recommend ways, or provide a reference for future decisions or simply to assist understanding of the past. Therefore, the results of the tested hypotheses can serve this purpose. The outcomes can be used for practitioners as future decision references.

The tested hypotheses using the two developed methodologies provide the understanding of the past on the relationships between investment, the use of technology and manufacturing performance, especially on RoS, TFP and value added growth. The aspects of interaction effect between investment and technology and multiple performance measures have been proposed for the consideration of future decisions. The changes in these relationships studied from the 1980s to the 1990s are also provided, such as the diminishing positive effects of cumulative investment and technology usage on manufacturing performance from the 1980s to the early 1990s. In addition, the three forms of investment have been investigated to amend the gap in investment analysis in this area.

8.4   Recommendations for Further Work

This research has developed two methodologies for manufacturing practice and performance relationship studies, in which two models have been formed and applied. However, there are other models available in econometric analysis which are worth investigating to contribute to the methodology development on quantitatively evaluating manufacturing practice and performance relationship in

the future. Specifically, the panel data estimation should be considered using relevant modelling techniques if a panel data is available.

Therefore, a database, including a wide range of factors related to performance, is required to be developed or gathered to investigate the gaps discovered in chapter 5, which can not be studied in this research. For example, the effects of external economic factors or firm performance are desirable, with the consideration of internal factors at the same time.

Further research into the span of investment projects can be useful to understand why it took about six years' cumulated investment to reach the best effect on performance in the 1980s. Interaction effect of cumulative investment and the use of technology on manufacturing performance in the early 1990s could be further investigated when a larger database would be available in the future. For gathering such a database for a relative long period is constrained by many factors, such as the accessibility of companies and the relative stability of the manufacturing sector for the whole business. It is very difficult to construct such a database because it is also subject to financial status and the time limit of the project as well.

As far as the measurement of technology usage index is concerned, an improvement can be made in further research to consider the degree of the integrated technologies and the life cycle of a technology, which is impossible to investigate in this research due to further detailed data on technology usage being required. A recent research has stated that using integrated technologies can be important for their performance (Small & Yasin, 1997) and in turn to impact manufacturing company performance. The degree of integration of technologies and the complexity of technologies can be considered to evaluate the effect of technology usage on performance in the future. In addition, the factors related to the life cycles of technologies can be considered to understand the changes of effect of the use of technology on manufacturing performance improvement. The different stages of the use of technologies such as implementing new

technologies, maintaining existing technologies, and leveraging mature technology can be included in future studies to understand the changes of technologies through the different periods. Detailed information on technology usage has to be available during the data collection period to ensure the possibility of further research into these factors. These factors can be considered in the future research designs.

An investigation of the split between contribution to RoS and to growth can be a recommendation for further study due to no suitable methodology for further investigation being available for this issue during the time, which this research has been conducted.

Moreover, the extension of the database from the 1980s into the early 1990s uncovers a weak survival performance of these UK manufacturing companies. The lower survival rate (average 60%) of UK manufacturing companies within this database is also supported by government reports. Investigating the factors that may be essential for manufacturing companies' survival can be valuable for future decisions. Therefore, further research into the survival behaviours of UK manufacturing companies has been proposed and funding granted by the Leverhulme Trust.

References

Amit, R. and Schoemaker, P. (1998), Strategic Assets and Organisational Rent, in *The Strategy Reader*, edited by Segal-Horn, S., Blackwell Business, the Open University, pp. 200-219.

Anderson, T. W. (1984), *An Introduction to Multivariate Statistical Analysis*, 2nd edition, John Wiley & Sons. Inc.

Arnold, V. L., Bardhan, I. R., Cooper, W. W. and Kumbhakar, C. (1996), New Uses of DEA and Statistical Regressions for Efficiency Evaluation and Estimation – with An Illustrative Application to Public Secondary Schools in Texas, *Annals of Operations Research*, vol. 66, pp. 255-277.

Arthur, J. B. (1994), Effect of Human Resource Systems on Manufacturing Performance and Turnover, *Academy of Management Journal*, vol. 37, no. 3, pp. 670-687.

Banker, R., Potter, G. and Schroeder, R. (1993), Manufacturing Performance Reporting for Continuous Quality Improvement, *Management International Review*, vol. 33, 1st quarter, Special issue, pp. 69-85.

Bao, B. H. and Bao, D. H. (1989), An Empirical Investigation of the Association between Productivity and Firm Value, *Business Finance & Accounting*, vol. 16, no. 5, Winter, pp. 203-215.

Beardwell, I. J. (1996), *Contemporary Industry Relations*, Edited, Oxford University Express.

Bessant, J. (1991), *Managing Advanced Manufacturing Technology*, Blackwell.

Blackaby, D. H. and Hunt, L. C. (1993), An Assessment of Britain's Productivity Record in the 1980s, in *Britain's Economic Miracle, Myth or Reality*, edited by Healey, N. M., Routledge, London, pp. 109-126.

Brown, B. And Saks, D. (1980), Production Technologies and Resource Allocation within Classrooms and Schools: Theory and Measurement, *The Analysis of Educational Productivity*, Edited by Dreeben, R. and Thomas, J. A., vol. 1, Cambridge: Ballinger.

Buckley, P. J., Pass, C. L. and Prescott, K. (1990), The Implementation of an International Market Servicing Strategy in UK Manufacturing Firms, *British Journal of Management*, vol. 1, pp. 127-136.

Calantone, R. J., Vickery, S. K. and Droge, C. (1995), Business Performance and Strategic New Product Development Activities: An Empirical Investigation, *Production Innovation Management Journal*, vol. 12, pp. 214-223.

Capon, N. Farley, J. U. and Hoenig, S. (1990), Determinants of Financial Performance: a Meta-Analysis, *Management Science*, vol. 36, no. 10, pp. 1143-59.

Carpano, C., Chrisman, J. J. and Roth, K. (1994), International Strategy and Environment: An Assessment of the Performance Relationship, *Journal of International Business Studies*, Third quarter, pp. 639-656.

Carr, C. (1988), Strategy Alternatives for Vehicle Component Manufacturers, *Long Range Planning*, vol. 21, no. 4, pp. 86-97.

Chaganti. R. and Damanpour F. (1991), Institutional Ownership, Capital Structure, and Firm Performance, *Strategic Management Journal*, vol. 12, pp. 479-491.

Chang, Y. and Thomas, H. (1989), The Impact of Diversification Strategy on Risk-Return Performance, *Strategic Management Journal*, vol. 10, pp. 271-284.

Chatfield, C. and Collons, A. J. (1980). *Introduction to Multivariate Analysis*, Chapman & Hall, 2-6 Baundary Row, London, pp. 153-159.

Chizmar, J. F. and Zak, T. A. (1983). Modelling Multiple Outputs in Educational Production Functions, *American Economic Review*, vol. 73, pp. 18-22.

Clode, D. M. (1993), A Survey of UK Manufacturing Control over the Past Ten Years, *Production and Inventory Management Journal*, Second Quarter, pp. 53-56.

Coombs, R. (1988), Technology Opportunities and Industrial Organisation, in *Technological Change and Economic Theory*, edited by Dosi, G., Freeman C., Nelson, R., Silverberg, G. and Soete, L. Pinter Publishers, pp. 295-308.

Corbett, L. M. and Harrison, N. J. (1992), Manufacturing Performance and Employee Involvement, *International Studies of Management and Organization*, vol. 22, no. 4 Winter, pp. 21-32.

Covin, J. G. and Slevin D. P. (1989), Strategic Management of Small Firms in Hostile and Benign Environments, *Strategic Management Journal,* vol. 10, no. 1, pp. 75-87.

Cronbach, L. J. (1987), Statistical Tests for Moderator Variables: Flows in Analyses Recently Proposed, *Psychological Bulletin*, vol. 102, no. 3, pp. 414-417.

Dasgupta, S., Sarkis J. and Talluri, S. (1999), Influence of Information Technology Investment on Firm Productivity: a Cross-sectional Study, *Logistics Information Management*, vol. 12, no. 1/2, pp. 120-129.

Doornik, J. A., Arellano, M and Bond, S. (1999), Panel Data Estimation using DPD for Ox, *Working Papers, Neffield College*, Oxford.

Dougherty, C. (1992), *Introduction to Econometrics*, Oxford University Press.

Douglas, E. J. (1987), *Managerial Economics: Analysis and Strategy*, 3rd Edition, Prentice-Hall, Inc.

Draper, N. and Smith, H. (1981), *Applied Regression Analysis*, John Wiley & Sons, Inc.

Dubois, F. L., Toyne, B. and Oliff, M. D. (1992), International Manufacturing Strategies of US Multinationals: A Conceptual Framework based on a Four-Industry Study, *Journal of International Business Studies*, Second quarter, pp. 307-333.

Dunlap W. P. and Kemery E. R. (1987), Failure to Detect Moderating Effects: Is Multicollinearity the problem, *Psychological Bulletin,* vol. 102, no. 3, pp. 418-420.

Evan, W. M. (1966), Organisational Lag, *Human Organisation,* vol. 25, pp. 51-53.

Evans, D. S. (1987), The Relationship between Firm Growth, Size, and Age: Estimates for 100 Manufacturing Industries, *The Journal of Industrial Economics*, vol. xxxv, no. 4, June, pp. 567-581.

Fisher, J. (1992), Use of Nonfinancial Performance Measures, *Cost Management*, Spring, pp. 31-38.

Fitzgerald, W. V. (1997), 'PITT Crews' Foster New Relationships, Better Performance, *Plant Engineering*, vol. 51, no. 9, August, pp. 78-82.

Fowler, K. L. and Schmidt, D. R. (1989), Determinants of Tender offer Post-Acquisition Financial Performance, *Strategic Management Journal*, vol. 10, pp. 339-350.

Freeman, C. and Perez, C. (1988), Structural Crises of Adjustment, Business Cycles and investment Behaviour, *in Technological Change and Economic Theory*, edited by Dosi, G., Freeman C., Nelson, R., Silverberg, G. and Soete, L. Pinter Publishers, pp. 38-66.

Friedrich R. J. (1982), In defense of Multiplicative Terms in Multiple Regression Equations, *American Journal of Political Science*, vol. 26, no. 4, November, pp. 797-833.

Galloway, R. L. (1993), *Principles of Operations Management*, Routledge, London.

Garsombke, T. W. and Garsombke, D. J. (1989), Strategic Implications Facing Small Manufacturers: The Linkage Between Robotization, Computerization, Automation and Performance, *Journal of Small Business Management*, vol. 27, No. 4, pp. 34-44.

Glass, G. V. (1976), Primary, Secondary and Meta-Analysis of Research, *Educational Research*, vol. 5, pp. 3-8.

Glass, G. V., McGaw, B. and Smith, M. L. (1981), *Meta-Analysis in Social Research*. Beverly Hills, CA: Sage.

Glyn, (1989), *The Macro-anatomy of the Thatcher Years, in The Restructuring of the UK Economy,* edited by Green, F, Brighton: Harvester Wheat-sheaf.

Grant, R. (1998), The Resource-Based Theory of Competitive Advantage: Implications for Strategy Formulation, in *The Strategy Reader*, edited by Segal-Horn, S., Blackwell Business, the Open University, pp. 179-199.

Greene, W. H. (1991), *Limdep: User's Manual and Reference Guide*, Econometric Software, Inc.

Greene, W. H. (1993), *Econometrics Analysis*, Macmillan Publishing Company.

Greenley, G. E. (1986), Does Strategic Planning Improve Company Performance, *Long Range Planning*, vol. 19, no. 2, pp. 101-109.

Gooding, R. Z. and Wagner III, J. A. (1985), A Meta-Analytic Review of the Relationship between Size and Performance: the Productivity and Efficiency of Organisations and their Subunits, *Administrative Science Quarterly*, vol. 30, pp. 462-481.

Griffin, A., Gleason, G., Preiss, R. and Shevenaugh, D. (1995), Best Practice for Customer Satisfaction in Manufacturing Firms, *Sloan Management Review*, Winter, pp. 87-98.

Groves, G. (1988), The Effectiveness of AMT Investment in UK Clothing Manufacture, Study Report, September.

Groves, G. and Hamblin, D. J. (1990), The Effectiveness of AMT Investment in UK Electronics Manufacture, Study Report, August.

Habib, M. M. and Victor, B. (1991), Strategy, Structure, and Performance of US Manufacturing and Service MNCs: A Comparative Analysis, *Strategy Management Journal*, vol. 12, pp. 589-606.

Hamblin, D. J. (1989), The Effectiveness of AMT Investment in UK Fluid Handling Equipment Manufacture, Study Report, December.

Hamblin, D. J. (1990), The Effectiveness of AMT Investment Decisions in the UK Process Machinery Industry, *Advanced Manufacturing Engineering*, vol. 2, no. 3, pp. 161-168.

Hamblin, D. J. and Iyer, A. (1996), What Difference does Your Industry Make?, *International Journal of Production Economics*, vol. 43, pp. 155-174.

Hamblin, D. J. and Lettman, A. (1996), Manufacturing Investment-Performance Causality in the UK Clothing Industry, *International Journal of Production Research*, vol. 34, no. 9, pp. 2421-2440.

Hansen, G. S. and Wernerfelt, B. (1989), Determinants of Firm Performance: The Relative Importance of Economic and Organizational Factors, *Strategic Management Journal*, vol. 10, Sep./Oct. pp. 399-411.

Harrison, M. (1990) *Advanced Manufacturing Technology Management*, Pitman.

Healey, N. M. (1993), *Britain's Economic Miracle, Myth or Reality*, Edited, Routledge, London.

Hodges, J. and Hamblin, D. J. (1989), The Effectiveness of AMT Investment in UK Process Machinery Manufacture, Study Report, *Private Communication to the Members of the British Federation of Printing Machines & Supplies*, January.

Hunter, J. E., Schmidt, F. L., and Jackson, G. B. (1982), *Meta-Analysis: Cumulating Research Findings Across Studies*, Beverly Hills, CA: Sage.

Ito, K. and Pucik, V. (1993), R&D Spending, Domestic Competition, and Expert Performance of Japanese Manufacturing Firms, *Strategic Management Journal*, vol. 14, pp. 61-75.

Jaccard J., Turrisi R. and Wan C. (1990), *Interaction Effects in Multiple Regression*, Series/No 07-072, Sage Publications, Inc.

Kaplan, R. and Norton, D. (1992), The Balanced Scorecard Measures that Drive Performance, *Harvard Business Review*, Jan./Feb., pp. 71-79.

Kaplan, R. and Norton, D. (1993), Putting the Balanced Scorecard to Work, *Harvard Business Review*, Sep/Oct. 1993, vol. 71, no. 5, pp. 134-142.

Kaplan, R. and North, D. (1996), Linking the Balanced Scorecard to Strategy, California Management Review, Fall, vol. 39, no. 1, pp. 53-79.

Kasul, R. A. and Motwani, J. G. (1995), Total Quality Management in Manufacturing: Thematic Factor Assessment, *International Journal of Quality & Reliability Management*, vol. 12, no. 3, pp. 57-76.

Kay, J. (1993), *Foundations of Corporate Success*, Oxford University Press.

Kitson, M and Michie, J. (1996), Britain's Industrial Performance Since 1960: Underinvestment and Relative Decline, *Economic Journal: The Journal of the Royal Economic Society*, vol. 106, No. 434, Jan, pp. 196-212.

Li, X and Hamblin, J.D. (1996), A Meta-Analytic Review of the Relationships between Practice and Performance in Manufacturing Industry, *the Proceedings of the Twelfth National Conference on Manufacturing Research*, University of Bath, pp. 411-415.

Li, X and Hamblin, D. J. (1997), The Effect of Investment and Technology on UK Manufacturing Company Performance, *the Proceedings of the Thirteen National Conference on Manufacturing Research*, Glasgow, pp. 290-294.

Li, X and Hamblin, D. J. (1998a), Revisiting the Effects of Investment and Technology on UK Manufacturing Company Performance, *the Proceedings of the fifth Conference of European Operations Management Association*, Dublin, pp. 291-297.

Li, X and Hamblin, D. J. (1998b), Relating Investment and Technology to A Multivariate Manufacturing Company Performance, *the Proceedings of the Performance Measurement: Theory and Practice*, Cambridge University, pp. 428-435.

Macduffie, J. P. (1995), Human Resource Bundles and Manufacturing Performance: Organizational Logic and Flexible Production System in the World Auto Industry, *Industrial and Labour Relations Review,* vol. 48, no. 2, January, pp. 197-221.

Maskell, B. H. (1991), *Performance Measurement for World Class Manufacturing: A Model for American Companies*, Productivity Press, Inc.

Mayer, R. (1987), Winning Strategies for Manufacturers in Mature Industries, *Journal of Business Strategies*, vol. 8, no. 2, pp. 23-30.

Maynard, G. (1993), Britain's Economic Recovery, in *Britain's Economic Miracle, Myth or Reality*, edited by Healey, N. M., Routledge, London, pp. 57-71.

McGrath, M. E. and Romeri, M. N. (1994), From Experience/The R&D Effectiveness Index: A Metric for Product Development Performance, *Journal of Production and Innovation Management*, vol. 11, pp. 213-220.

Meyer, A. D. and Ferdows, K. (1990), Influence of Manufacturing Improvement Programmes on Performance, *International Journal of Operations and Production Management,* vol. 10, no. 2, pp. 120-131.

Neuman, W. L. (1999), *Social Research Methods: Qualitative and Quantitative Approaches*, Allyn & Bacon.

Ng, I. and Maki, D. (1993), Human Resource Management in the Canadian Manufacturing Sector, *International Journal of Human Resource Management,* vol. 4, no. 4, pp. 987-916.

Nicholson, N. and Brooks-Rooney, A. (1990), Strategy, Innovation and Performance, *Journal of Management Studies,* vol. 27, no. 5, September, pp. 511-534.

Nolan, P. (1996), Industrial Relations Since 1945, in *Contemporary Industry Relations, A Critical Analysis,* edited by Beardwell, I. J., Oxford, pp. 99-120.

Oldcorn, R. and Parker, D. (1996), *Strategic Investment Decision*, PITMAN Publishing.

Oliver, N., Delbridge, R., Jones, D. and Lowe, J. (1994), World Class Manufacturing: Further Evidence in the Lean Production Debate, *British Journal of Management,* vol. 5, Special issue, pp. S53-S63.

O'Mahony, M. (1994), Can Britain Bridge the Productivity Gap?, *Long Range Planning,* vol. 27, no. 2, pp. 85-94.

Oulton, N. (1989), Productivity Growth in Manufacturing, 1963-85: The Roles of New Investment and Scrapping, *National Institute Economic Review,* February, pp. 64-75.

Pearlman, K., Schmidt, F. L. and Hunter, J. E. (1980), Validity Generalization Results for Tests Used to Predict Job Proficiency and Training Success in Clerical Occupations, *Journal of Applied Psychology,* vol. 65, pp. 373-405.

Peter, J. P. (1979), Reliability: A Review of Psychometric Basics and Recent Marketing Practices, Journal of Marketing Research, vol. XVI, Feb., pp. 6-17.

Peters, L. H., Hartke, D. D. and Pohlmann, J. T. (1985), Fiedler's Contingency Theory of Leadership: An Application of the Meta-Analysis Procedures of Schmidt and Hunter, *Psychological Bulletin,* vol. 97, pp. 274-285.

Porter, M. (1998), *Competitive Advantage: Creating and Sustaining Superior Performance*, The Free Press.

Powell, T. (1996), How Much does Industry Matter? An Alternative Empirical Test, *Strategic Management Journal*, vol. 17, no. 4, pp. 323-334.

Prahalad, C. K. and Hamel, G. (1998), The Core Competence of the Corporation, in *The Strategy Reader*, edited by Segal-Horn, S., Blackwell Business, the Open University, pp. 220-233.

Primrose, P. L. and Leonard, R. (1986), The Financial Evaluation and Economic Application of Advanced Manufacturing Technology, *the Proceeding of the Institute Mechanical Engineering*, 200, B1, pp. 27-32.

Radder, L. and Louw, L. (1998), The SPACE Matrix: A Tool for Calibrating Competition, *Long Range Planning*, Vol. 31, No. 4, pp. 549-559.

Richardson, P. R., Taylor, A. J. and Gordon, J. R. M. (1985), A Strategic Approach to Evaluating Manufacturing Performance, *Interface*, vol. 15, no. 6, Nov.-Dec., pp. 15-27.

Rosenthal, R. and Rubin, D. (1982), A Simple, General Purpose Display of Magnitude of Experimental Effect, *Journal of Educational Psychology*, vol. 74, pp. 166-169.

Roth, A. V. and Miller, J. G. (1992) Success Factors in Manufacturing, *Business Horizons*, vol. 35, no. 4, pp. 73-81.

Rumelt, R. (1991), How Much Does Industry Matter? *Strategic Management Journal,* vol. 12, no.3, pp. 167-185.

Sa, J. V. (1988), The Impact of Key Success Factors on Company Performance, *Long Range Planning,* vol. 21, no. 6, pp. 56-64.

Saunders D. R. (1956), Moderator Variables in Prediction, *Educational and Psychological Measurement,* vol. 16, pp. 209-222.

Schmalansee, R. (1985), Do Markers Differ Much? *American Economic Review*, vol. 75, no. 3, pp.341-351.

Schmenner, R. W. and Rho, B. H. (1989), An International Comparison of Factory Productivity, *International Journal of Operations and Production Management,* vol. 10, no. 4, pp. 16-31.

Schmidt, F. L., Gast-Rosenberg, I. and Hunter, J. E. (1980), Validity Generalization Results for Computer Programmers, *Journal of Applied Psychology*, vol. 65, pp. 643-661.

Schmidt, F. L., Hunter, J. E. And Caplan, J. R. (1981), Validity Generalization Results for Two Job Groups in the Petroleum Industry, *Journal of Applied Psychologist*, vol. 66, pp. 261-273.

Sellani, R. J. (1994), Organizational Lag and Its Effects on Financial Performance, *Production and Inventory Management Journal*, Third Quarter, pp. 77-81.

Shadur, M. A. (1995), Total Quality-Systems Survive, Cultures Change, *Long Range Planning*, vol. 28, no. 2, pp. 115-125.

Silver, M. S. and Lowe, J. F. (1989), An Appraisal of the Performance of Manufacturing Industry in Wales, *Journal of Economic Studies*, vol. 16, no. 1, pp. 31-46.

Slack, N., Chambers, S., Harland, C., Harrison, A. and Johnston, R. (1995), *Operations Management*, PITMAN Publishing.

Small, M. and Yasin, M. M. (1997), Advanced Manufacturing Technology: Implementation Policy and Performance, *Journal of Operations Management*, vol. 15, no. 4. November, pp. 349-370.

Smith, K. W. and Sasaki, M. S. (1979), Decreasing Multicollineraity, A Method for Models with Multiplicative Function, *Sociological Methods & Research*, vol. 8, no. 1, August, pp. 35-56.

Spiegel, M. R. (1972), *Theory and Problems of Statistics*, McGRAW-Hill Book Co.

Stonier, A. W. and Hague, D. C. (1972), *A Textbook of Economic Theory*, the Fourth Edition, Longman.

Sultan, F., Farley, J. U. and Lehmann, D. R. (1989), A Meta-Analysis of Applications of Diffusion Models, *Journal of Marketing Research*, vol. 27, pp. 70-77.

Swanson, L. (1997), Empirical Study of the Relationship between Production Technology and Maintenance Management, *International Journal of Production Economics,* vol. 53, no. 2, November, pp. 191-207.

Tate, R. L. (1984), Limitations of Centering for Interactive Models, *Sociological Methods & Research,* vol. 13, no. 2, November, pp. 251-271.

Terborg, J. R., Lee, T. W., Smith, F. J., Davis, G. A. and Turbin, M. S. (1982), Extension of the Schmidt and Hunter Validity Generalization Procedure to the Prediction of Absenteeism Behavior from Knowledge of Job Satisfaction and Organizational Commitment, *Journal of Applied Psychology*, vol. 67, pp. 440-449.

Tofallis, C. (1997a), Modelling Best-Practice Frontiers when There are Multiple Outputs, in *Advances in Multiple Objective & Goal Programming*, edited by Caballero, R., Ruiz, F. and Steuer, R. E. Springer, pp. 382-397.

Tofallis, C. (1997b), Model Building with Multiple Dependent Variable, *Working Papers, ESDS Department, University of Hertfordshire.*

Tunalv, C. (1992), Manufacturing Strategy-Plans and Business Performance, *International Journal of Operations & Production Management,* vol. 12, No. 3, pp. 4-24.

Uri, N. D. (1988), A Re-examination of the Relationship between Industry Structure and Economic Performance, *Applied Economics*, vol. 20. Oct. pp. 1383-1400.

Vinod, H. D. (1968). Econometrics of Joint Production, *Econometrica,* vol. 36, April, pp. 322-336.

Vinod, H. D. (1969). Econometrics of Joint Production--A Reply, *Econometrica,* vol. 37, October, pp. 739-740.

Vinod, H. D. (1976). Canonical Ridge and Econometrics of Joint Production, *Journal of Econometrics,* vol. 4, May, pp. 147-166.

Voss, C. A. (1986), Managing New Manufacturing Technologies, *Operations Management Association*, Monograph 1.

Voss, C., Blackmon, K., Hanson, P. and Oak, B. (1995), The Competitiveness of European Manufacturing-A Four Country Study, *Business Strategic Review*, vol. 6, no. 1, pp. 1-25.

Wacker, J. G. (1987), The Complementary Nature of Manufacturing Goals by Their Relationship to Throughput Time: A Theory of Internal Variability of Production Systems, *Journal of Operations Management*, vol. 7, nos. 1 and 2, pp. 91-106.

Wathen, S. (1995), Manufacturing Strategy in Business Units: An Analysis of Production Process Focus and Performance, *International Journal of Operations & Production Management*, vol. 15, no. 8, pp. 4-13.

Werberfelt, B. and Montgomery, C. (1988), Tobin's Q and the Importance of Focus in Firm Performance, *American Economic Review*, vol.78, pp. 246-251.

Wolf, F. M. (1986), *Meta-Analysis: Quantitative Methods for Research Synthesis,* Beverly Hills, Sage.

Wright, M., Dobson, P. Thompson, S. and Robbie, K. (1992), How Well Does Privatisation Achieve Government Objectives? The Case of Bus-Buy-Outs, *International Journal of Transport Economics*, vol. XIX, no. 3, October, pp. 259-285.

Wright, M., Thompson, S. and Robbie, K. (1989), Privatisation via Management and Employee Buyouts, *Annals of Public and Co-operative Economy*, vol. 60, pp. 399-429.

Young, S. M., Shields, M. D. and Wolf, G. (1988), Manufacturing Controls and Performance: An Experiment, *Accounting Organization and Society*, vol. 13, no. 6, pp. 607-618.

Zairi, M. (1992), *Management of Advanced Manufacturing Technology*, Sigma.

Zedeck S. (1971), Problems with the Use of "Moderator Variables", *Psychological Bulletin*, vol. 79, pp. 295-310.

Appendix 1   The Studies Included in this Meta-Analysis

Armstrong, J. S., (1991), Strategic Planning Improves Manufacturing Performance, *Long Range Planning*, vol. 24, no. 4, pp. 127-129

*Arthur, J. B., (1994), Effects of Human Resource Systems on Manufacturing Performance and Turnover, *Academy of Management Journal*, vol. 37, no. 3, pp. 670-687

Banker, R., Potter, G. and Schroeder, R., (1993), Manufacturing Performance Reporting for Continuous Quality Improvement, *Management International Review*, vol. 33, 1st quarter, Special issue, pp. 69-85

*Bao, B. H. and Bao, D. H., (1989), An Empirical Investigation of the Association between Productivity and Firm Value, *Business Finance & Accounting*, vol. 16, no. 5, Winter, pp. 203-215

Bozarth, C. C., (1993), A Conceptual Model of Manufacturing Focus, *International Journal of Operation and Production Management*, vol. 13, no. 1, pp. 81-92

Buckley, P. J., Pass, C. L. and Prescott, K., (1990), The Implementation of an International Market Servicing Strategy in UK Manufacturing Firms, *British Journal of Management,* vol. 1, pp. 127-136

*Calantone, R. J., Vickery, S. K. and Droge, C., (1995), Business Performance and Strategic New Product Development Activities: An Empirical Investigation, *Production Innovation Management Journal*, vol. 12, pp. 214-223

*Carpano, C., Chrisman, J. J., and Roth, K., (1994), International Strategy and Environment: An Assessment of the Performance Relationship, *Journal of International Business Studies*, Third quarter, pp. 639-656

Carr, C., (1988), Strategy Alternatives for Vehicle Component Manufacturers, *Long Range Planning*, vol. 21, no. 4, pp. 86-97

*Chaganti. R. and Damanpour F., (1991), Institutional Ownership, Capital Structure, and Firm Performance, *Strategic Management Journal*, vol. 12, pp. 479-491

*Chang, Y. and Thomas, H., (1989), The Impact of Diversification Strategy on Risk-Return Performance, *Strategic Management Journal*, vol. 10, pp. 271-284

Clode, D. M., (1993), A Survey of UK Manufacturing Control over the Past Ten Years, *Production and Inventory Management Journal*, Second Quarter, pp. 53-56

*Covin, J. G. and Slevin D. P., (1989), Strategic Management of Small Firms in Hostile and Benign Environments, *Strategic Management Journal,* vol. 10, no. 1, pp. 75-87

Corbett, L. M. and Harrison, N. J., (1992), Manufacturing Performance and Employee Involvement, *International Studies of Management and Organization*, vol. 22, no. 4 Winter, pp. 21-32

Dubois, F. L., Toyne, B. and Oliff, M. D., (1992), International Manufacturing Strategies of US Multinationals: A Conceptual Framework based on a Four-Industry Study, *Journal of International Business Studies*, Second quarter, pp. 307-333

*Evans, D. S., (1987), The Relationship Between Firm Growth, Size, and Age: Estimates for 100 Manufacturing Industries, *The Journal of Industrial Economics*,

vol. xxxv, no. 4, June, pp. 567-581

*Fowler, K. L. and Schmidt, D. R., (1989), Determinants of Tender offer Post-Acquisition Financial Performance, *Strategic Management Journal*, vol. 10, pp. 339-350

*Garsombke, T. W. and Garsombke, D. J., (1989), Strategic Implications Facing Small Manufacturers: The Linkage Between Robotization, Computerization, Automation and Performance, *Journal of Small Business Management*, vol. 27, no. 4, pp. 34-44

Greenley, G. E., (1986), Does Strategic Planning Improve Company Performance, *Long Range Planning*, vol. 19, no. 2, pp. 101-109

Griffin, A., Gleason, G., Preiss, R. and Shevenaugh, D., (1995), Best Practice for Customer Satisfaction in Manufacturing Firms, *Sloan Management Review*, Winter, pp. 87-98

Habib, M. M. and Victor, B., (1991), Strategy, Structure, and Performance of US Manufacturing and Service MNCs: A Comparative Analysis, *Strategy Management Journal*, vol. 12, pp. 589-606

*Ito, K. and Pucik, V., (1993), R&D Spending, Domestic Competition, and Export Performance of Japanese Manufacturing Firms, *Strategic Management Journal*, vol. 14, pp. 61-75

Kasul, R. A. and Motwani, J. G., (1995), Total Quality Management in Manufacturing: Thematic Factor Assessment, *International Journal of Quality & Reliability Management*, vol. 12, no. 3, pp. 57-76

*Macduffie, J. P., (1995), Human Resource Bundles and Manufacturing Performance: Organizational Logic and Flexible Production System in the World Auto Industry, *Industrial and Labour Relations Review*, vol. 48, no. 2, January, pp. 197-221

Mayer, R., (1987), Winning Strategies for Manufacturers in Mature Industries, *Journal of Business Strategies*, vol. 8, no. 2, pp. 23-30

McGrath, M. E. and Romeri, M. N., (1994), From Experience/The R&D Effectiveness Index: A Metric for Product Development Performance, *Journal of Production and Innovation Management*, vol. 11, pp. 213-220

*Meyer, A. D. and Ferdows, K., (1990), Influence of Manufacturing Improvement Programmes on Performance, *International Journal of Operations and Production Management*, vol. 10, no. 2, pp. 120-131

Meyer, D. G. and Cooke, W. N., (1993), US Labour Relations in Transition: Emerging Strategies and Company Performance, *British Journal of Industrial Relations*, vol. 31, no. 4, pp. 531-552

Mowshowitz, A., (1989), On Managing Technological Change, *Technovation*, vol. 9, pp. 623-633

Ng, I. and Maki, D., (1993), Human Resource Management in the Canadian Manufacturing Sector, *International Journal of Human Resource Management*, vol. 4, no. 4, pp. 987-916

Oliver, N., Delbridge, R., Jones, D. and Lowe, J., (1994), World Class Manufacturing: Further Evidence in the Lean Production Debate, *British Journal of Management*, vol. 5, Special issue, pp. S53-S63

O'Mahony, M., (1994), Can Britain Bridge the Productivity Gap?, *Long Range Planning*, vol. 27, no. 2, pp. 85-94

Outlon, N., (1989), Productivity Growth in Manufacturing, 1963-85: The Roles of

New Investment and Scrapping, *National Institute Economic Review*, February, pp. 64-75

*Richardson, P. R., Taylor, A. J. and Gordon, J. R. M., (1985), A Strategic Approach to Evaluating Manufacturing Performance, *Interface*, vol. 15, no. 6, Nov.-Dec., pp. 15-27

Roth, A. V. and Miller, J. G., (1992) Success Factors in Manufacturing, *Business Horizons*, vol. 35, no. 4, pp. 73-81

*Sa, J. V., (1988), The Impact of Key Success Factors on Company Performance, *Long Range Planning,* vol. 21, no. 6, pp. 56-64

Sawaya, W. J., (1993), Improving Company Performance Through Operations Management Training for Production Workers, *Production and Inventory Management Journal*, Second Quarter, pp. 18-22

Schmenner, R. W. and Rho, B. H., (1989), An International Comparison of Factory Productivity, *International Journal of Operations and Production Management,* vol. 10, no. 4, pp. 16-31

Sellani, R. J., (1994), Organizational Lag and Its Effects on Financial Performance, *Production and Inventory Management Journal*, Third Quarter, pp. 77-81

Shadur, M. A., (1995), Total Quality-Systems Survive, Cultures Change, *Long Range Planning*, vol. 28, no. 2, pp. 115-125

Shetty, Y. K., (1993), Aiming High: Competitive Benchmarking for Superior Performance, *Long Range Planning*, vol. 26, no. 1, pp. 39-44

*Silver, M. S. and Lowe, J. F., (1989), An Appraisal of the Performance of Manufacturing Industry in Wales, *Journal of Economic Studies*, vol. 16, no. 1, pp. 31-46

Tunalv, C., (1992), Manufacturing Strategy-Plans and Business Performance, *International Journal of Operations & Production Management,* vol. 12, No. 3, pp. 4-24

Wacker, J. G., (1987), The Complementary Nature of Manufacturing Goals by Their Relationship to Throughput Time: A Theory of Internal Variability of Production Systems, *Journal of Operations Management*, vol. 7, nos. 1 and 2, pp. 91-106

Wathen, S., (1995), Manufacturing Strategy in Business Units: An Analysis of Production Process Focus and Performance, *International Journal of Operations & Production Management*, vol. 15, no. 8, pp. 4-13

Young, S. M., Shields, M. D. and Wolf, G., (1988), Manufacturing Controls and Performance: An Experiment, *Accounting Organization and Society*, vol. 13, no. 6, pp. 607-618

* The studies are also included in the second form (measuring effect size approach) of the meta-analysis.

Authors	Dependent variables	Independent variables	Size	Methods	Findings
Calantone et. al. (1995)	RoI, RoI growth, market share, market share growth, RoS and RoS growth	8 NPD activities	65	Correlation analysis	A strong positive influence of the NPD activities on RoI, RoS, market share and their growth
Garsombke and Garsombke (1989)	The total performance index (including 26 factors)	Use of technology Automation Robotization computerisation	144	Correlation analysis and multiple linear regression analysis	The advanced technology benefits performance. Robotics and computerisation are positively related to performance, but not automation.
Chaganti and Damanpour (1991)	Debt-capital ratio, profitability, RoA, RoE, P-E ratio, otal stock return	Stock ownership	80	Correlation analysis and regression analysis	The significant effect of the size of the outsider stockholdings on the firms' capital structure. Other moderators are existent to the firm' capital structure and performance.
Chang and Thomas (1989)	Return-the average of Ros over five years Risk-the variance of RoA	Diversification, size of the firm (assets)	64	Multiple linear regression analysis	Diversification did not affect return and risk; Return influenced the choice of diversification.
Sa (1988)	RoA	R&D, technology, diversification, labour relations focus	190	Multiple linear regression analysis	The five key factors index have been developed for three types of manufacturers.
Ito and Pucik (1993)	Export performance- export sales and ratio. Domestic sales	R&D spending (firm and industry R&D intensity and amount), firm size, domestic market position	266	Correlation analysis and multiple regression analysis (log)	Export sales are positively associated with R&D expenditures, firm size, average R&D intensity of an industry. A firm's export ratio is related to its size but not R&D intensities.
Fowler and Schmidt (1989)	Long-term financial performance measured by the averages of RoCE and RSH of the five years (75-79)	Firm size, age, acquisition experience, industry commonality, hostility, percentage of stock acquired	42	Correlation analysis and stepwise regression analysis	Acquisition experience brought improvement of performance in the post-acquisition firm. The hostility in target firms was not good for post-acquisition performance.

Table A.1. Continued

Author	Dependent variable	Independent variable	Size	Methods	Findings
Evans (1987)	Firm growth, the variability of firm growth and firm dissolution	Firm size, firm age and the number of plants in a firm	42,339	Multiple regression analysis (log)	Firm growth decreases with firm size and age. The probability of firm survival increases with firm size and age. The variability of firm growth decreases with firm age.
Bao and Bao (1989)	Firm value-earnings per share	Productivity (added value)	57	Correlation analysis and multiple linear regression analysis	By improving productivity, a firm should be able to use its scarce resources more efficiently while increasing profit margin and increasing its value.
Meyer and Ferdows (1990)	Eight Performance indicators (quality, cost, inventory, on-time delivery, delivery speed, overhead costs, batch sizes, etc.)	36-39 actions programmes form the 1986 and 1987 surveys	32	Stepwise regression analysis	Most of the action programmes were benefiting performance improvements, especially production control and cost reduction.
Richardson et. al. (1985)	Profitability-profit after tax plus R&D as a percentage of sales	Corporate and plants focuses, firm size, cost, the level of mission	64	Correlation analysis and multiple linear regression analysis	An important factor in corporate success is the degree to which the perceived corporate mission matches the measures of performance of the manufacturing function.
Macduffie (1995)	Labour productivity and quality	HR practices, use of buffers, work systems, HRM policies and production organization index, etc.	62	Correlation analysis and multiple interaction regression analysis	Innovative HR practices affect performance as interrelated elements in a HR 'bundle'; and these HR bundles contribute most to assembly plant productivity and quality when they are integrated with manufacturing policies.
Arthur (1994)	Labour efficiency-labour hours and quality-scrap rate	Human resource system, turnover, age, size, union status, business strategy	30	Correlation analysis and multiple interaction regression analysis	The mills with commitment systems had higher productivity, lower scrap rates and lover employee turnover than those with control systems.

Table A.1. Continued

Author	Dependent variable	Independent variable	Size	Methods	Findings
Carpano et. al. (1994)	The rate of their foreign subsidiaries' RoI and sales growth against the performance of their competitors	Segmentation strategy construct (4), geographic scope strategy (3) and environment variables (6)	33 (I) 75 (B)	Correlation analysis and t-test	Geographic scope and segment differentiation can be used to distinguish four international strategies, the effectiveness of which is a function of the environment in which firms complete.
Covin and Slevin (1989)	Financial performance criteria includes: sales level, sales growth rate, cash flow, return on shareholder equity, gross profit margin, net profit from operations, profit to sales ratio, RoI, and ability to fund business growth from profit. The degree of satisfaction.	Environment hostility, organization structure and strategic posture	161	Multiple interaction regression analysis	Performance among small firms in hostile environments was positively related to an organic structure, an entrepreneurial strategic posture, a competitive profile characterized by a long-term orientation, high product prices and a concern for predicting industry trends.
Silver and lowe (1989)	Labour productivity	Capital to labour ratio	1561	Multiple regression analysis (log)	Labour productivity per employee is strongly related to *per capita* income and differences of nearly two per cent are not to be ignored. The higher UK labour productivity than Wales was found not to be generalised across all industries.

Table A.1 Summary of the studies included in the second form of the meta-analysis

Appendix 2   Open-ended Questionnaire Used for the Inter-Company Interviews

Data of Initial Visit:
Company
Address

Tel:

Contacts   Position

Industrial Sector

Products

Date Founded
Parent Company
Ownership private or public
Subsidiaries

Wholly owned site
Single or multiple site
Production Areas
Details about the company and re-organisation

Operational Philosophy

Autonomy of the Company

Basic of Investment Strategy and Asset Purchase

Machine Lease or Purchase
How critical is AMT to the business
State-of-the-art Equipment

Strategic Plan
Budgeting Plan
Method of Justification of Investment
Post Audit of Investment

Product

Main Product Lines, Customers and Markets
1,
2,
3,

Maximum sales to 1 customer
Degree of specialisation of product
Number of customers

Extent of customer relations & commitment

Number of Products
% Customised
Primary Material
Product Sophistication
Product sold as item or assembly
Extent of Sales Team
Use of Agents or Distributors
Own transport
Main Growth Areas

Rate of new product introduction
Main Product Driver
Main Company Driver
Main Customer Demands
Use of factoring
Inter-company trading

% Export   Export Regions

Market Share
Main Competitors and Country of Origin

Design

Extent and capabilities of the Design Team

Use of centralised design team

Use of CAD, CAE, CADCAM - Type, Benefits, timings, utilisation, suitability

Use of licence build
Product, development time, life cycle etc.

Production

Details of Production equipment/processes and in-house operations

Use of AMT
Reason for using AMT and main effects

Type of equipment, make, axis, No. of pallets, FMS etc.

% of Production by AMT
DNC Link or MDI-(background/on line)
Use of robots etc.
% normal production subcontracted
% proprietary e.g. tooling
Reasons for subcontracting, quality, priorities etc.

Type of Production, Batch or Flow
Average Batch Size
Average Lead Time
Stability of Order Book
% Build to Stock
% Free Issue Material
Tolerances

Number of shifts worked   AMT   Non-AMT
Use of JIT, GT, TQM, MRP etc.

Factory layout

Machine age
Machine Utilisation   AMT   Non-AMT
Maintenance Practises

In-house or subcontract
Reliability of equipment   AMT   Non-AMT

Details of Production Control System and their Integration

Use of EDI

Quality

Details of Quality Standards and Customer Approval
BS5750 registered
AQAP approved

Vendor rating systems
TQM, Quality circles
SPC
Process Capability
The importance of Quality to the Company

Details of inspection capability and methods

Co-ordinate measuring machine
Reason for purchase of CMM

Effectiveness of CMM

Staffing

Skill level of workforce
Flexible use of workforce
Use of overtime
Labour Turnover rate
Difficulty in recruiting labour
Emphasis on Training Schemes
Type of Payment and incentive schemes

Appendix 3   Numerical Data Collected for the Original Database

The following numerical data have been collected from 1979 to 1988:

- Turnover
- Materials
  - Total
  - Materials
  - Components
  - Subcontract
- Depreciation
- Lease
  - Rent building
  - Rent computers
- Employment cost
- Subcontract
  - Labour
  - Services
- Redundancy costs
- Profit before tax
- Stocks
  - Total
  - Materials/components
  - Work in process
  - Finished good
- Spend
  - Land/building
  - Non-AMT
  - AMT
    - Assembly
    - Test
    - Design
    - Computers
- Fixtures
- Transport
- R&D
- NBV
  - land and building
  - other assets
- Trade Debtors
- Trade Creditors
- Capital Grants
- Revenue Grants
- Employees
  - Total
  - Administration
  - Engineering

- Production
- Quality
- Marketing
- Apprentices
- Labour turnover
- Depreciation period

Appendix 4   The List of Technologies as AMT in the Questionnaires in the Original Database

Clothing Sector:

Computer Aided Design (CAD) in use in 1983 and 1987

Computers for administration and control in use in 1983 and 1987
      Computer Business System
      Computerised Manufacturing Planning and Control (including MRP)
      Integration Systems (including CIM)

Advanced manufacturing technologies in production in use in 1983 and 1987
      CNC Cutting
      CNC Garment Assembly
      CNC Knitting

Electronics Sector:

Computer Aided Design (CAD)

Computers for administration and control
      Computer Business System
      Computerised Manufacturing Planning and Control (including MRP)
      Integration Systems (including CIM)

Advanced manufacturing technologies in production
      Computerised Insertion/Assembly
      Computerised Test
      Robotics

Fluid Handling and Special Machinery:

Computer Aided Design (CAD)

Computers for administration and control
      Computer Business System
      Computerised Manufacturing Planning and Control (including MRP)
      Integration Systems (including CIM)

Advanced manufacturing technologies in production
      Computer-Assisted Manufacturing (including CNC, DNC, FMS)
      Computer-Assisted Production Planning
      Robotics

Appendix 5   The Questionnaires of Technology Usage for the Extended Database

Clothing Sector:
Please answer the following five questions. Thank you very much for your co-operation.

Company's Name:_____

Address:_____

Tel:_____   Fax:_____

(1) Which of following Advanced Manufacturing Technologies (AMT) have been employed in your company in the 90's and for how many years has it been used?

	Please tick relevant ones	Year(s)
Group 1: DESIGN		
Computer-Assisted Design (including Lay Planning)	☐	___
Group 2: PRODUCTION		
CNC Cutting	☐	___
CNC Garment Assembly	☐	___
CNC Knitting	☐	___
Others (please specify)		
_____	☐	___
Group 3: MANAGEMENT AND CONTROL		
Computerised Business Systems	☐	___
Computerised Manufacturing Planning and Control (including MRP)	☐	___
Integration Systems (Including CIM)	☐	___

(2) What proportion of the activities is done by the AMT?

	Proportion(%)				
	20	40	60	80	100
Design	—	—	—	—	—
Production	—	—	—	—	—
Management and Control	—	—	—	—	—

(3) How satisfied are you that the AMT meets your current needs?

	very poor	poor	adequate	good	excellent
Design	—	—	—	—	—
Production	—	—	—	—	—
Management and Control	—	—	—	—	—

(4) To what extent has the AMT been replaced over the last 10 years?

	Not at all	Partially	Totally
Design	—	—	—
Production	—	—	—
Management and Control	—	—	—

(5) What is the typical current utilisation of your AMT in production?

No. of Shifts   _____   Utilisation   _____

☐ Please tick here if you would like a copy of the results of the study.

Corresponding name:_____

Electronics Sector:

Please answer the following five questions. Thank you very much for your co-operation.

Company's Name:_____
Address:_____
Tel:_____   Fax:_____

(1) Which of following Advanced Manufacturing Technologies (AMT) have been employed in your company in the 90's and for how many years has it been used?

	Please tick relevant ones	Year(s)
Group 1: DESIGN		
Computer-Assisted Design	☐	___
Group 2: PRODUCTION		
Computerised Insertion/Assembly	☐	___
Computerised Test	☐	___
Robotics	☐	___
Others (please specify)		
_____	☐	___
Group 3: MANAGEMENT AND CONTROL		
Computerised Business Systems	☐	___
Computerised Manufacturing Planning and Control (including MRP)	☐	___
Integration Systems (Including CIM)	☐	___

(2) What proportion of the activities is done by the AMT?

	Proportion(%)				
	20	40	60	80	100
Design	__	__	__	__	__
Production	__	__	__	__	__
Management and Control	__	__	__	__	__

(3) How satisfied are you that the AMT meets your current needs?

	very poor	poor	adequate	good	excellent
Design	__	__	__	__	__
Production	__	__	__	__	__
Management and Control	__	__	__	__	__

(4) To what extent has the AMT been replaced over the last 10 years?

	Not at all	Partially	Totally
Design	__	__	__
Production	__	__	__
Management and Control	__	__	__

(5) What is the typical current utilisation of your AMT in the production?

No. of Shifts   _____   Utilisation   _____

☐ Please tick here if you would like a copy of the results of the study.
Corresponding name:_____

Fluid Handling and Special Machinery

Please answer the following five questions. Thank you very much for your co-operation.

Company's Name:_____

Address:_____

Tel:_____   Fax:_____

(1) Which of following Advanced Manufacturing Technologies (AMT) have been employed in your company in the 90's and for how many years has it been used?

	Please tick relevant ones	Year(s)
Group 1: DESIGN		
Computer-Assisted Design	☐	___
Group 2: PRODUCTION		
Computer-Assisted Manufacturing (including CNC, DNC, FMS)	☐	___
Computer-Assisted Production Planning	☐	___
Robotics	☐	___
Others (please specify)		
_____	☐	___
Group 3: MANAGEMENT AND CONTROL		
Computerised Business Systems	☐	___
Computerised Manufacturing Planning and Control (including MRP)	☐	___
Integration Systems (Including CIM)	☐	___

(2) What proportion of the activities is done by the AMT?

	Proportion(%)				
	20	40	60	80	100
Design	—	—	—	—	—
Production	—	—	—	—	—
Management and Control	—	—	—	—	—

(3) How satisfied are you that the AMT meets your current needs?

	very poor	poor	adequate	good	excellent
Design	—	—	—	—	—
Production	—	—	—	—	—
Management and Control	—	—	—	—	—

(4) To what extent has the AMT been replaced over the last 10 years?

	Not at all	Partially	Totally
Design	—	—	—
Production	—	—	—
Management and Control	—	—	—

(5) What is the typical current utilisation of your AMT in production?

_____ No. of Shifts   _____   Utilisation   _____

☐ Please tick here if you would like a copy of the results of the study.

Corresponding name:_____

253

Appendix 6   An Example of the Programmes of Limdep for Stage 1's Models

This is an example of one part of programmes written in Limdep, in which centralisation, interaction and lag effects have been considered for 1979's investment and 1980's RoS.

```
? After centralising the independent variables (sp_lb and techinde),
? the multiplicative interactions between them in different years are
? tested by a two-step regression model (with and
? without an interaction (product) term of these two variables).
? investment in a single year and without time lag

Sample     ;all$
Reject     ;ROS80=0+SP_lb79=0+techinde=0$
Regress    ;Lhs=Ros80;Rhs=one,sp_lb79$
Calc       ;M_SPlb79 = Xbr(SP_lb79)$
Calc       ;M_techin = Xbr(techinde)$
Create     ;Csp_lb79 = SP_lb79 - M_splb79$
Create     ;Ctechin = techinde - M_techin$
Regress    ;Lhs=ROS80;Rhs=one,Csp_lb79,Ctechin$
Create     ;Cinter79=Csp_lb79*Ctechin$
Regress    ;Lhs=ROS80;Rhs=one,Csp_lb79,Ctechin,Cinter79$
```

Appendix 7 An illustration of Application of Maximum Correlation Using Solver in Excel

Inv.	Tech.	Inter	X	RoS	Growth	Y
x_{11}	x_{21}	$x_{11}x_{21}$	$\alpha_1 x_{11}+\alpha_2 x_{21}+\alpha_3 x_{11}x_{21}$	y_{11}	y_{21}	$\beta_1 y_{11}+\beta_2 y_{21}$
x_{21}	x_{22}	$x_{21}x_{22}$	$\alpha_1 x_{11}+\alpha_2 x_{21}+\alpha_3 x_{11}x_{21}$	y_{12}	y_{22}	$\beta_1 y_{11}+\beta_2 y_{22}$
.	.	.	.	.	.	.
.	.	.	.	.	.	.
.	.	.	.	.	.	.
α_{11}	α_{22}	α_{33}		β_{11}	β_{22}	

The coefficients α_{11}, α_{22}, α_{33}, β_{22} are obtained by maximising correlation (X, Y) under the constraints of all coefficients positive and $\beta_{11}=1$, using Solver.

Appendix 8 The Characteristics of the Sample for the Period from 1979 to 1988

Variables		N	Mean	Min	Median	Max	S. D.
RoS (%)	79	83	5.83	-92.20	6.60	36.01	13.80
	80	95	5.47	-45.35	6.07	36.06	10.20
	81	103	3.44	-175.47	6.25	40.40	22.84
	82	118	6.16	-35.93	5.53	35.00	8.82
	83	138	5.23	-105.13	5.04	34.64	12.58
	84	153	6.20	-48.88	6.69	35.45	10.17
	85	163	6.79	-36.02	6.84	34.31	9.27
	86	168	6.36	-104.99	6.60	47.18	13.54
	87	122	6.63	-56.57	7.54	34.63	11.97
	88	74	8.03	-27.74	8.64	33.89	10.68
TFP	79	56	1.68	0.42	1.57	4.77	0.63
	80	67	1.69	0.84	1.54	7.95	0.87
	81	82	1.63	0.33	1.55	4.47	0.53
	82	108	1.65	0.91	1.59	4.11	0.48
	83	130	1.66	0.12	1.56	4.14	0.55
	84	145	1.76	0.60	1.64	6.71	0.70
	85	156	1.76	0.68	1.66	4.33	0.59
	86	165	1.80	0.65	1.68	4.84	0.55
	87	114	1.84	0.44	1.71	4.82	0.61
	88	73	1.84	0.53	1.78	3.64	0.54
Investment (-land and building)/ Value added (%)	79	69	6.47	0.00	4.93	52.69	6.93
	80	84	4.96	-0.59	3.63	44.29	5.57
	81	95	7.52	0.00	3.73	109.16	15.16
	82	114	6.17	-0.59	3.96	50.00	8.24
	83	133	6.73	0.00	4.90	70.68	8.09
	84	151	7.88	0.00	5.22	131.01	12.83
	85	160	7.87	0.03	5.60	101.05	9.77
	86	167	7.74	0.00	5.23	220.00	17.15
	87	123	6.47	-0.71	5.68	28.51	4.86
	88	73	14.07	0.24	6.05	430.64	50.18
Technology Index		173	43.98	9.00	38.00	100.00	24.56

Appendix 9   The Coefficients of the Models in a Single Year's Investment without Time Lag in the 1980s

RoS	Model										
	6.9		6.11		6.12			6.14			
	a	β_1	a	β_2	a	β_1	β_2	a	β_1	β_2	β_3
88	7.961	-0.086	7.951	0.099	7.968	-0.079	0.071	8.551	0.019	0.087	0.003
87	6.516	-0.034	6.530	0.100	6.515	-0.040	0.100	6.509	-0.005	0.098	0.005
86	6.281	-0.487	6.179	0.066	6.170	-0.489	0.072	6.007	-0.337	0.094	0.020
85	6.806	-0.227	6.818	0.085	6.806	-0.256	0.097	6.697	-0.276	0.099	0.004
84	6.128	-0.077	6.123	0.089	6.131	-0.079	0.091	6.020	-0.060	0.094	0.008
83	5.036	-0.710	5.001	0.047	5.039	-0.748	0.085	4.706	-0.851	0.096	0.011
82	6.059	0.317	6.050	0.079	6.059	0.276	0.063	5.799	0.144	0.067	0.007
81	2.736	-0.824	2.749	0.149	2.736	-0.890	0.243	1.424	-1.182	0.138	0.021
80	5.138	-0.650	5.136	-0.021	5.133	-0.662	0.012	5.655	-0.240	0.013	-0.019
79	6.118	-1.456	6.126	-0.093	6.106	-1.514	0.052	7.809	-0.697	0.032	-0.033

Appendix 10 The Coefficients Of the Models in a Single Year's Investment with One to Three Years' Time Lag (m = 1, 2, 3) in the 1980s

RoS	Model 6.9		Model 6.12			Model 6.14			
	a	β_1	a	β_1	β_2	a	β_1	β_2	β_3
m = 1									
88	8.477	-0.034	8.478	-0.035	0.070	8.475	0.030	0.069	0.006
87	6.377	-0.049	6.380	-0.047	0.099	6.422	0.033	0.110	0.006
86	7.431	0.307	7.429	0.286	0.071	7.454	0.290	0.070	-0.001
85	6.796	-0.007	6.799	-0.009	0.100	6.740	0.001	0.102	0.004
84	5.920	0.037	5.919	0.011	0.057	5.416	-0.145	0.073	0.017
83	5.763	0.317	5.767	0.294	0.036	5.498	0.157	0.041	0.007
82	5.953	-0.046	5.954	-0.069	0.084	5.991	-0.061	0.087	-0.001
81	2.443	-0.069	2.444	-0.213	0.158	2.363	-0.278	0.158	0.003
80	5.025	-0.755	5.437	-0.796	0.038	6.505	-0.284	0.026	-0.021
m = 2									
88	8.680	0.024	8.677	0.029	0.076	9.342	0.302	0.130	0.015
87	7.335	-0.272	7.336	-0.283	0.093	7.206	-0.290	0.097	0.009
86	7.300	-0.004	7.298	-0.006	0.099	7.282	-0.003	0.099	0.001
85	6.856	-0.071	6.858	-0.101	0.068	6.630	-0.172	0.075	0.008
84	5.624	0.395	5.624	0.379	0.024	5.386	0.258	0.029	0.007
83	5.769	0.017	5.768	0.006	0.038	5.829	0.020	0.043	-0.001
82	6.015	0.054	6.015	-0.010	0.070	6.072	0.035	0.070	-0.002
81	2.277	0.022	2.279	-0.181	0.186	3.748	0.524	0.169	-0.029
m = 3									
88	8.858	0.056	8.860	0.065	0.099	9.005	0.102	0.110	0.008
87	7.059	-0.035	7.056	-0.032	0.103	7.241	0.022	0.114	0.007
86	6.801	-0.028	6.802	-0.065	0.086	6.512	-0.155	0.097	0.010
85	6.736	0.283	6.738	0.252	0.049	6.468	0.115	0.054	0.007
84	5.877	0.058	5.874	0.054	0.011	5.927	0.066	0.015	-0.001
83	5.600	0.120	5.600	0.089	0.034	5.874	0.308	0.034	-0.010
82	6.216	-0.001	6.215	-0.055	0.054	6.605	0.151	0.047	-0.008

Appendix 11   The Significant Results of Lagged Model when m=4, 5, 6 in the 1980s

RoS	Model																	
	m=4						m=5						m=6					
	6.9	6.12		6.14			6.8	6.12		6.14			6.9	6.12		6.14		
	Inv.	Inv.	Tec.	Inv.	Tec.	Int.	Inv.	Inv.	Tec.	Inv.	Tec.	Int.	Inv.	Inv.	Tec.	Inv.	Tec.	Int.
88			++		++	++	++		++	++			++	++				
87			++		++	++	+	+			+	++			++			
86	++	++	++		++	++			++		++							
85			+															
84													▓	▓	▓	▓	▓	▓
83							▓	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓

+, –: Significantly positive or negative at 10% level
++, —: Significantly positive or negative at 5% level
☐: The model is not significant at 10% level
▓: No relevant period for the delay effects

Appendix 12 The Characteristics of the Sample for the Period from 1989 to 1995

Variables		N	Mean	Min	Median	Max	S. D.
RoS (%)	89	28	9.35	-2.26	7.04	57.90	11.57
	90	29	5.75	-9.03	5.86	22.88	8.53
	91	36	3.56	-13.66	3.28	22.51	9.84
	92	38	2.02	-13.23	2.51	14.96	9.52
	93	38	1.49	-28.22	3.15	19.64	11.22
	94	40	2.04	-29.38	3.68	20.03	11.72
	95	38	8.83	-13.05	4.73	118.37	21.95
TFP	89	28	2.25	0.44	1.69	3.17	4.73
	90	29	1.73	0.44	1.62	3.27	4.93
	91	36	2.09	0.40	1.85	9.90	5.70
	92	38	1.82	0.40	1.67	3.74	5.75
	93	39	1.89	0.46	1.90	3.95	5.83
	94	40	1.95	0.46	1.84	3.44	5.90
	95	38	1.97	0.54	1.87	3.56	5.72
Investment (-land and building)/ Value added (%)	89	28	6.76	0.18	5.29	33.12	7.6
	90	28	7.75	0.91	5.59	36.32	8.39
	91	32	10.84	0.03	6.31	56.51	12.63
	92	35	8.01	0.45	4.20	67.49	13.13
	93	38	6.40	0.90	4.38	47.60	9.06
	94	39	5.27	0.05	4.16	18.31	6.68
	95	36	5.93	0.11	4.16	35.86	8.53
Technology Index		45	63.05	25.95	63.29	100	17.06

Appendix 13 The Coefficients of the Models in a Single Year's Investment without Time Lag (m=0) in the Early 1990s

TFP	Model										
	6.9		6.11		6.12			6.14			
	a	β_1	a	β_2	a	β_1	β_2	a	β_1	β_2	β_3
95	1.991	-0.007	1.991	0.005	1.991	-0.010	0.006	1.984	-0.013	0.006	0.000
94	1.984	0.000	1.984	0.000	1.984	0.000	0.000	1.980	-0.001	0.001	-0.001
93	1.891	-0.027	1.891	0.003	1.891	-0.029	0.005	1.865	-0.041	0.005	0.001
92	1.812	-0.018	1.812	0.003	1.812	-0.020	0.006	1.859	-0.004	0.002	-0.001
91	1.764	-0.031	1.764	-0.014	1.764	-0.029	-0.006	1.721	-0.036	-0.004	0.001
90	1.709	-0.030	1.709	-0.020	1.709	-0.024	-0.018	1.724	-0.017	-0.019	-0.001
89	2.713	-0.148	2.713	-0.031	2.713	-0.180	-0.025	2.673	-0.217	-0.034	0.005

Appendix 14 **The Coefficients of the Models of Lag Effect of Investment in a Single Year, Technology Usage and their Interaction on TFP in the Early 1990s**

TFP	Model 6.9		Model 6.12			Model 6.14			
	a	β_1	a	β_1	β_2	a	β_1	β_2	β_3
	Investment 89								
95	1.863	-0.011	1.863	-0.010	-0.007	1.852	-0.019	-0.009	0.001
94	1.875	-0.030	1.875	-0.028	-0.014	1.871	-0.032	-0.014	0.001
93	1.770	-0.046	1.770	-0.045	-0.009	1.766	-0.049	-0.010	0.001
92	1.747	-0.047	1.747	-0.046	-0.007	1.747	-0.046	-0.007	-0.000
91	1.804	-0.041	1.804	-0.039	-0.013	1.801	-0.041	-0.014	0.000
90	1.716	-0.036	1.716	-0.033	-0.020	1.711	-0.038	-0.021	0.001
	Investment 90								
95	1.889	-0.019	1.889	-0.017	-0.005	1.887	-0.019	-0.005	0.000
94	1.847	-0.031	1.847	-0.027	-0.011	1.859	-0.022	-0.011	-0.001
93	1.801	-0.029	1.801	-0.027	-0.007	1.832	-0.013	-0.008	-0.002
92	1.749	-0.029	1.749	-0.028	-0.005	1.770	-0.018	-0.006	-0.001
91	1.791	-0.031	1.791	-0.028	-0.011	1.816	-0.017	-0.012	-0.001
	Investment 91								
95	1.881	-0.018	1.881	-0.017	-0.002	1.860	-0.020	-0.001	0.000
94	1.884	-0.022	1.884	-0.018	-0.009	1.882	-0.019	-0.009	0.000
93	1.799	-0.024	1.779	-0.023	-0.003	1.780	-0.026	-0.003	0.000
92	1.770	-0.023	1.770	-0.025	-0.002	1.723	-0.030	0.000	0.001
	Investment 92								
95	1.945	-0.002	1.945	-0.003	0.004	1.981	0.008	0.002	-0.001
94	1.936	-0.008	1.936	-0.008	-0.002	2.011	0.016	-0.008	-0.002
93	1.875	-0.017	1.875	-0.018	0.005	1.931	0.000	-0.000	-0.002
	Investment 93								
95	1.972	-0.006	1.972	-0.008	0.007	1.952	-0.018	0.006	0.001
94	1.919	-0.018	1.919	-0.019	0.002	1.922	-0.018	0.002	-0.000
	Investment 94								
95	2.011	-0.005	2.011	-0.004	0.007	2.004	-0.005	0.007	-0.001

Appendix 15 The Significant Results of the Effects of Cumulative Investment on Manufacturing Performance by RoS

RoS	80	81	82	83	84	85	86	87	88
Inv79-80	—								
Inv80-81		—							
Inv81-82					+	+	++	++	++
Inv82-83				++	++	++	++	++	++
Inv83-84					+			+	++
Inv84-85								—	
Inv85-86							++	—	
Inv86-87									
Inv87-88									

+, −. Significant positive or negative at 10% level
++, —. Significant positive or negative at 5 % level

Table A15.1. The effect of a two-year period's investment on manufacturing performance (RoS)

RoS	81	82	83	84	85	86	87	88
Inv79_81	—							
Inv80_82			+	++	+	++	+	++
Inv81_83				+	++	++	++	++
Inv82_84				++	++	++	++	++
Inv83_85						+		++
Inv84_86							—	
Inv85_87							—	
Inv86_88								

+, −. Significantly positive or negative at 10% level
++, —. Significantly positive or negative at 5 % level

Table A15.2. The effect of a three-year period's investment on manufacturing performance (RoS)

RoS	82	83	84	85	86	87	88
Inv79-82							
Inv80-83		++	++	+	++	++	++
Inv81-84			++	++	++	++	++
Inv82-85				++	++	++	++
Inv83-86					+		++
Inv84-87						—	
Inv85-88							

+, −. Significantly positive or negative at 10% level
++, – –. Significantly positive or negative at 5 % level

Table A15.3. The effect of a four-year period's investment on manufacturing performance (RoS)

RoS	83	84	85	86	87	88
Inv79-83						
Inv80-84		++	++	++	++	++
Inv81-85			++	++	++	++
Inv82-86				++	++	++
Inv83-87						++
Inv84-88						

+, −. Significantly positive or negative at 10% level
++, −−. Significantly positive or negative at 5 % level

Table A15.4. The effect of a five-year period's investment on manufacturing performance (RoS)

RoS	84	85	86	87	88
Inv79-84	+		++	+	+
Inv80-85		++	++	++	++
Inv81-86			++	++	++
Inv82-87				+	++
Inv83-88					++

+, −. Significantly positive or negative at 10% level
++, −−. Significantly positive or negative at 5 % level

Table A15.5. The effect of a six-year period's investment on manufacturing performance (RoS)

RoS	85	86	87	88
Inv79-85	+	+		
Inv80-86		++	++	++
Inv81-87				+
Inv82-88				

+, −. Significantly positive or negative at 10% level
++, −−. Significantly positive or negative at 5 % level

Table A15.6. The effect of a seven-year period's investment on manufacturing performance (RoS)

Appendix 16 The Coefficients of the Models in Six Years' Cumulative Investment, Technology Usage, their Interaction and RoS in the 1980s

RoS	Model 6.10		Model 6.13			Model 6.15			
	a	β_1	a	β_1	β_2	a	β_1	β_2	β_3
	Inv79-84								
88	6.502	0.107	6.502	0.092	0.099	6.401	0.086	0.103	0.000
87	7.558	0.062	7.558	0.057	0.044	7.294	0.035	0.036	0.002
86	7.161	0.063	7.161	0.058	0.040	6.998	0.037	0.033	0.001
85	6.893	0.055	6.893	0.051	0.032	6.696	0.026	0.023	0.002
84	5.597	0.081	5.597	0.084	-0.027	5.412	0.061	-0.035	0.002
	Inv80-85								
88	7.183	0.123	7.183	0.118	0.048	7.364	0.139	0.051	-0.001
87	7.639	0.066	7.639	0.064	0.025	7.494	0.050	0.013	0.002
86	6.997	0.077	6.997	0.073	0.027	6.903	0.064	0.021	0.001
85	6.727	0.069	6.727	0.064	0.033	6.574	0.049	0.023	0.001
	Inv81-86								
88	7.969	0.112	7.969	0.109	0.078	7.968	0.108	0.078	0.000
87	8.116	0.066	8.116	0.063	0.026	7.850	0.050	0.014	0.002
86	7.230	0.065	7.230	0.059	0.033	7.077	0.050	0.027	0.001
	Inv82-87								
88	7.794	0.097	7.794	0.092	0.057	7.621	0.075	0.051	0.002
87	7.411	0.063	7.411	0.057	0.040	7.187	0.044	0.036	0.002
	Inv83-88								
88	8.421	0.100	8.421	0.100	0.050	8.408	0.091	0.048	0.001

Appendix 17 **The Comparison of Significance of Technology Usage between the Full Sample and the Smaller Sample with the Consistent Six Years' Investment.**

RoS	Inv.	The Full Size			The Small Size		
		N	Adj. R^2	P value	N	Adj. R^2	P value
88	79-84	71	0.039	**0.05**	19	0.035	0.21
	80-85				24	-0.007	0.37
	81-86				28	0.015	0.24
	82-87				37	0.010	0.25
	83-88				43	0.094	0.32
87	79-84	119	0.036	**0.02**	45	0.010	0.24
	80-85				53	-0.005	0.39
	81-86				61	0.005	0.25
	82-87				72	0.015	0.15
86	79-84	165	0.008	0.13	69	0.012	0.18
	80-85				83	0.007	0.21
	81-86				92	0.020	**0.09**
85	79-84	158	0.042	**0.005**	71	0.000	0.32
	80-85				85	0.007	0.21
84	79-84	132	0.040	**0.008**	71	-0.014	0.87

Bold number: significant results

Appendix 18 Significant Results of Cumulative Investment on TFP in the Early 1990s

TFP	90	91	92	93	94	95
Inv89-90	– –	– –	– –	– –	– –	
Inv90-91		– –	– –	– –	– –	– –
Inv91-92			– –	– –	–	
Inv92-93				–		
Inv93-94						
inv94-95						

Table A18.1   The Significant Results of Two Years Cumulative Investment

TFP	91	92	93	94	95
Inv89-91	– –	– –	– –	– –	–
Inv90-92		– –	– –	– –	
Inv91-93			– –	– –	
Inv92-94					
Inv93-95					

Table A18.2   The Significant Results of Three Years Cumulative Investment

TFP	92	93	94	95
Inv89-92	– –	– –	– –	
Inv90-93		– –	– –	
Inv91-94				
Inv92-95				

Table A18.3   The Significant Results of Four Years Cumulative Investment

TFP	93	94	95
Inv89-93	– –	– –	
Inv90-94		– –	
Inv91-95			

Table A18.4   The Significant Results of Five Years Cumulative Investment

TFP	94	95
Inv89-94	–	
Inv90-95		

Table A18.5   The Significant Results of Six Years Cumulative Investment

Appendix 19 The Comparison of the 1980s Effects on RoS and TFP between the Full Set and Sub-Set

RoS	Original Sample (175)					Sub-set (45)				
	Step1	Step2	Step3			Step1	Step2	Step3		
	Inv.	Tech.	Inv.	Tech.	Int.	Inv.	Tech.	Inv.	Tech.	Int.
88	– –	+		+		– –			+ +	+ +
87		++		++						
86	– –		– –	++	++	– –			+ +	+ +
85	– –	++	– –	++						
84	– –	++	– –	++	++					
83	– –		– –	++						
82	++	++		++		+ +	++			
81	– –		– –	++	++	+ +				
80	– –				– –					
79	– –		– –		– –					

'+' or '+ +': Significantly positive results of the coefficients at 10% or 5% level, resp.

'–' or '– –': Significantly negative results of the coefficients at 10% or 5% level, resp.

TFP	Original Sample (175)					Sub-set (45)				
	Step1	Step2	Step3			Step1	Step2	Step3		
	Inv.	Tech.	Inv.	Tech.	Int.	Inv.	Tech.	Inv.	Tech.	Int.
88	– –					– –				
87										
86	– –	+ +		+ +		– –				
85		+ +		+ +			+			
84	–					–				
83	– –		– –			–				
82										
81	– –		– –					– –	+ +	
80						– –		– –	+	
79					– –					

'+' or '+ +': Significantly positive results of the coefficients at 10% or 5% level, resp.

'–' or '– –': Significantly negative results of the coefficients at 10% or 5% level, resp.