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Measurement, Technology and International Trade: A Study in the Economics of Technology

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To the memory of my grandparents

"Weights and measures may be ranked among the necessaries of life to every individual of human society. They enter into the economical arrangements and daily concerns of every family. They are necessary to every occupation of human industry; to the distribution and security of every species of property; to every transaction of trade and commerce; to the labors of the husbandman; to the ingenuity of the artificer; to the studies of the philosopher; to the researches of the antiquarian; to the navigation of the mariner; and the marches of the soldier; to all the exchanges of peace, and all the operations of war. The knowledge of them, as in established use, is among the first elements of education, and is often learned by those who learn nothing else, not even to read and write. This knowledge is riveted in the memory by the habitual application of it to the employments of men throughout life."

John Quincy Adams

Report to the Congress, February 22, 1821

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Abstract

Economic activities comprising measurement embrace the science of metrology and its associated institutions, its diffusion through instrumentation and standardisation, and the use of measures by firms in their production and marketing activities. This thesis argues that the coherence of these activities provides a useful way of thinking about the role of technology in a modern economy. Emphasis is given throughout the thesis to the role of an 'infrastructure' of measurement in reducing transactions costs and enabling markets by assisting firms in the generation of product variety. The framework of measurement in an EU context is explored in chapter 2 of the thesis. The remainder of the thesis is devoted to a theoretical and empirical analysis of the role played by measurement in creating international trade and determining underlying patterns of trade.

Chapter 3 provides contextual background, considering the existing literature on the theoretical and empirical analysis of international trade, with emphasis on the role played by technology and innovation. The monopolistic competition model of international trade – which focuses on the generation of variety – is identified as providing a particularly suitable vehicle for the theoretical analysis of how measurement impacts upon international trade. This model is developed in chapter 4 in a way which allows for the public good effect of measurement infrastructure supplementing the role of market size in these models. The hypotheses developed suggest that the strength of this infrastructure across industries should be positively related to the generation of intra-industry trade. Chapters 5 and 6 provide the empirical analysis of the thesis. Chapter 5 embeds the idea of measurement into standard models of intra-industry trade in the context of bilateral trade in the EU. It is found that proxies or the strength of the infrastructure based upon industrial standards, as well as measures of the use of instruments, are important determinants of intra-industry trade. In chapter 6 the question of whether measurement infrastructure is associated with patterns of UK trade is addressed. It is found that the intensity of standard use by industry has a positive and significant associated effect with both UK exports and UK imports, but is not a source of comparative advantage for the UK. Chapter 7 of the thesis summarises and provides a concluding discussion.

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List of Acronyms

AFNOR	*Association Francaise de Normalisation*
ASTM	*American Society for Testing and Materials*
BCR	*Benefit-to-cost Ratio*
BIPM	*Bureau International des Poids et Measures*
BSI	*British Standards Institute*
CEE	*Central and Eastern Europe*
CEN	*European Committee for Standardization*
CENELEC	*European Committee for Electro technical Standardization*
CGPM	*General Conference on Weight and Measures*
CIA	*Central Intelligence Agency*
CINST	*Calculation of Measurement Instrument Consumption*
CIPM	*Comite International des Poids et Measures (International Committee of Weights and Measures)*
CMM	*Coordinate Measuring Machine*
DP	*Domestic Product*
DIN	*German Deutsches Institut fur Normung*
DTI	*Department of Trade and Industry (UK)*
EA	*European Accreditation*
EBM	*Economic Benefit Measure*
EC,EU	*European Commission, European Union*
ETSI	*European Telecommunications Standards Institute*
EURACHEM	*Measurement in Analytical Chemistry*
EUROLAB	*European Measurement and Testing Laboratories*
EUROMET	*European Collaboration in Measurement Standards*
FASCAL	*Facility for Automated Spectral Calibration*
FDI	*Foreign Direct Investment*
GDP	*Gross Domestic Product*
GNP	*Gross National Product*
GL	*Grubel and Lloyd index*
HIV/AIDS	*Human Immunodeficiency Virus/Acquired Immune Deficiency Syndrome*
H-O	*Heckscher-Ohlin Model*
IIT	*Intra-Industry Trade*
IRRM	*Institute for Reference Materials and Measurements*
ILAC	*International Accreditation*
ISDN	*Integrated Service Digital Network*
ISO	*International Organization for Standardization*

List of Acronyms – cont.

ISIC	*International Standards Industrial Classification*
LGC	*Laboratory of the Government Chemist*
IMF	*International Monetary Fund*
MER GDP	*Market Exchange Rate based GDP*
MID	*Measurement Instrument Directive*
MMI	*Mapping Measurement Impact*
MoU	*Memorandum of Understanding*
NIST	*US National Institute for Standards and Technology*
NMI	*National Measurement Institutions*
NMS	*National Measurement System*
NPL	*National Physical Laboratory*
NVP	*Net Present Value*
NSB	*National Standardization Bodies*
NTRM - NIST	*Traceable Referecne Materials*
NWML	*National Weights and Measures Laboratory*
OECD	*Organisation for Economic Cooperation and Development*
ONS	*National Statistics Online*
OIML	*International Legal Metrology*
OLS	*Ordinary Least Squares*
PMI	*Primary Metrology Institutes*
PPP GDP	*Purchasing Power Parities converted GDP*
R&D	*Research and Development*
RCA	*Revealed Comparative Advantage*
SI	*The International System of Units of Physical Quantities*
SIC	*Standard Industrial Classification*
SITC	*Standard International Trade Classification*
SME	*Small and Medium Sized Enterprises*
SQL	*Structured Query Language*
SRC	*Spearman Rank Correlation*
SRR	*Social Rate of Return*
STEP	*Standard for Exchange of Product*
TDIP	*Total Domestic Industry Product*
TFP	*Total Factor Producticity*
TUV NEL	*National Engineering Laboratory*
UKAS	*United Kingdom Accreditation Service*
WELMEC	*European Legal Metrology*
WLS	*Weighted Least Squares*

Chapter 1

Introduction

Economics has long recognized the contribution of technological change to economic growth. More recently increasing attention has been given to the role played by the purposive creation of knowledge as an explanatory factor in the complex processes of technical change. Here, the mechanisms involved are far less clear. This thesis is a study of one such mechanism, examining the role played by measurement in advanced economies – an activity which embraces both the science of metrology, the diffusion of that science through instrumentation and standardisation, and the attempts by firms to achieve competitive advantage through their own measurement activities. It is argued that measurement is a key factor underpinning the development of markets. Accordingly, and rather than looking directly at the contribution of measurement to output, the study seeks evidence from the impact of measurement on international trade, where the data is accurate and can be used at a highly disaggregated level. This chapter introduces the concept of measurement and provides an overview of the thesis.

Accurate measurement and traceable fundamental standards[1] of parameters are part of the language for engineers and scientists who use them to communicate with each other, to explore and understand the world. Seismologists measure the speeds at which seismic waves travel through the earth; ecologists measure the thickness of the North Pole ice to study the polar bear habitat; astronomers measure the dim light from distant stars to determine their age; meteorologists measure the density of carbon dioxide in the atmosphere to monitor

[1] Such as for time measurement, use caesium atomic clock measurement standards; for length dimensional metrology, use gauge blocks, line scales and depth micrometers measurement standards (Metrology – in short, 2003).

global warming, and recently genetic scientists have developed processes to measure the initial protein-DNA binding interactions that unleash the flow of information which, in turn, sparks gene expression. At the scientific level, measurement is a key element in what is sometimes known as the 'codified infrastructure' of that science to which the measurements pertain – what can usefully be measured when conducting experiments and how the results of experiments can be communicated to other scientists.

Measurement and standards are not solely for scientists and engineers. Everyday we rely on measurement techniques that enable us to make sound and reliable decisions. Doctors need accurate instruments to measure blood pressure and blood sugar level; bridge designers need precise site measurements to aid their design; pilots need reliable measurement of altitude and speed at all times; traffic wardens need the measurement of time, while roadside radar cameras now capture the speed at which we drive our cars - the list goes on.

The need for measurement in economic activity stems from the importance of product characteristics in both production processes and in terms of the characteristics which consumers actually desire. Innovation and product differentiation are frequently driven by changing or novel characteristics, or often new combinations of characteristics (Swann, 1999). Hence metrology plays a politically important role in trade and commerce, in helping to set up regulations concerning product qualities, and to reducing information asymmetries and hence helping to maintain fair trade. At the level of the individual firm, and in order to improve the quality of products and services and sustain or even increase profit, manufacturers and suppliers depend upon their ability to measure, ability to manufacture precisely services and products with precisely defined characteristics. For customers, they need to be confident of the quality and compliance of the product with the characteristics claimed by the producer. Sometimes these must be proven by reliable test reports and conformity assessments, often by reference to agreed reference materials. Moh's scale of reference materials for mineralogists is relatively familiar, providing a scale for 'scratch hardness' using reference materials from talc (=1) to a diamond (=10).

At a national level important claims have been made about the importance of measurement to economic growth as well as to international trade and competitiveness. Andrew Wallard, Director of Bureau International des Poids et Mesures (BIPM) has stated that there have been many studies showing a clear and very large techno-economic benefit from public investments in metrology. One recent UK study put the return from their £40m national investment at over £5bn (Temple and Williams, 2002b). Similar figures apply to economies of all sizes and stages of economic development. The benefits of metrology touch us all, wherever we live and whatever we do (Wallard, 2005).

Measurement therefore underpins much economic activity and arguably much technological change. Pioneering work by Tassey (1992) in the US has used the term 'infra-technology' to describe a varied set of 'technical tools' that include measurement and test methods, artefacts such as standard reference materials that allow these methods to be used efficiently, scientific and engineering databases, process models and the technical basis for both physical and functional interfaces between components of systems technologies such as factory automation and communications.

In the UK, work by Temple and Williams (2002b) suggest that – using patent data - measurement is vital to around 10% of patents and applying such a figure to research and development expenditures indicates that both investment and exports are extremely measurement intensive activities.

The concept of the measurement infrastructure is used in this thesis to elucidate the channels through which various aspects of measurement impact upon the economy, such as inducing technical progress to stimulate product innovation; improving productivity and product differentiation and then the support of international trade. As an important part of underpinning technologies, measurement in itself is mostly a non-productive but facilitating technology, which finally leads to economic growth. The simple reason is that measurement technologies are closely related with other forms of technology because they set the standards and scope of measurement to be carried out. Firms that invest in new technologies for the production process can gain a competitive edge. This is a good incentive to invest in research and development (R&D). For the longer term this leads to spillovers, which arise from the diffusion of the benefits of new technologies to the wider economy. The greater the level of R&D investment, the more innovations are created and the greater the economic growth.

Measures and measurement techniques can be regarded as a form of standard. Standards are documented, voluntary agreements that establish important criteria for products, services and processes. In modern parlance, a 'standard' is understood to be a set of technical specifications that can be adhered to by a producer, either tacitly, or in accordance with some formal agreement, or in conformity with an explicit regulatory authority (David and Steinmueller, 1994). Standards are the key mechanisms to ensure that products and services are fit for their purpose and are comparable and compatible. It is worth mentioning here that Spencer and Williams (2002) stated measurement and standards are interactive. Most standards adopt specific measures or measurement techniques and in turn the development of new measures or techniques can enable new standards either by allowing standards that were not formerly feasible or by allowing existing standards to be raised due to improved accuracy.

While the importance of measurement and standards on industry and society is gradually being recognised, little empirical literature has so far focused on the study of their effects on international trade, especially intra-industry trade (IIT) among regions and countries. This thesis aims to analyse the importance of measurement infrastructure in influencing the trade performance of the United Kingdom and European Union. It also attempts to shed some light on the potential sources of comparative advantage of the nations by different level of measurement infrastructure and how measurement infrastructure may be enhancing the ability of the firms in the United Kingdom to differentiate their products, thereby extending their market share.

In the following section the main structure of the thesis will be outlined, and then a brief summary of the main findings will be presented.

1.1 The Structure of the Thesis

Why then is measurement important from an economic perspective? This basic question forms the structure of this thesis. From an applied perspective, measurement provides a coherent set of economic activities that can be examined empirically. This – and the associated literature - is examined in chapter 2. It also develops two metrics of the measurement infrastructure, which are used in subsequent empirical analysis – the use of instruments and industrial standards.

From a theoretical point of view, one answer to this basic question lies in the contribution of measurement to the development of markets, and in ameliorating market failure. Chapters 3 and 4 take this idea further, exploring how technology relates to international specialisation and trade in chapter 3 that provides a literature review. It is argued that the monopolistic competition model of trade provides a suitable vehicle for integrating measurement into the theory of international trade and this is the approach adopted in chapter 4. The model developed there treats the measurement infrastructure as creating a 'public good' - a pool of feasible measurements which influences the ability of firms to differentiate their products. The model predicts that there is a positive relationship between the sophistication of measurement infrastructure and the level of intra-industry trade.

Chapters 5 and 6 develop econometric models to test some of the ideas developed by the theoretical framework. Firstly chapter 5 considers the case of the EU, since there are countries with similar capital endowments; the different measurement infrastructures are likely to be the source of potential comparative advantage which results in trade specialisation. The empirical results show that the average aggregate intensity of measurement instrument consumption has a positive effect on the extent of intra-industry trade. Chapter 6 investigates the role of measurement, specifically standards in the UK trade performance for the years 1993 to 2002. The empirical result indeed shows that the intensity of standards use by industry not only expands the UK's exports, but also boosted imports. The remainder of this chapter is devoted to summarizing the main conclusions of these chapters.

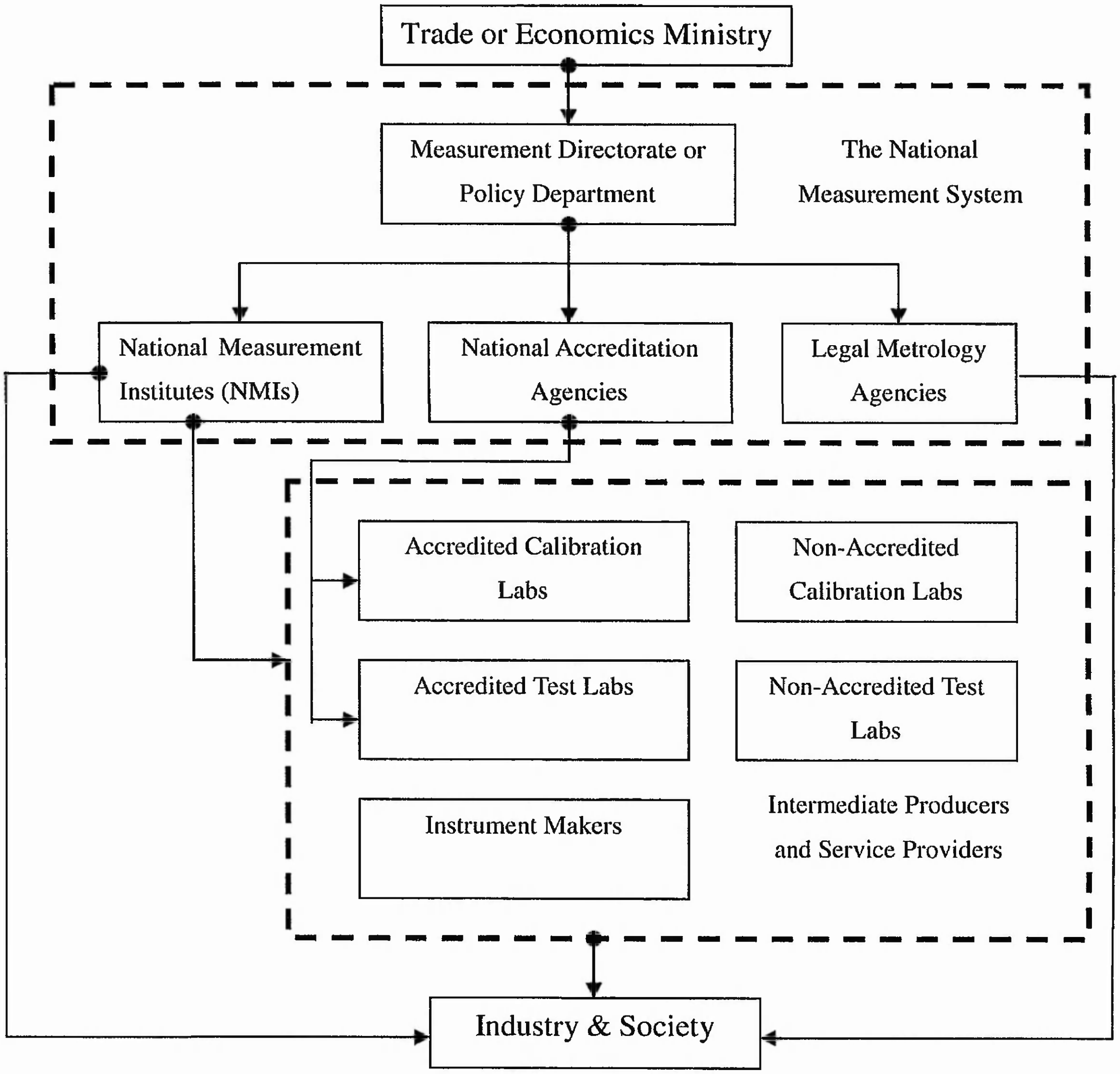
1.2 The Economic Structure of Measurement Activity

The empirical dimensions of measurement are discussed in chapter 2, which also examines some of the main literature sources to evaluate the impacts of measurement infrastructures.

In general, every country has a statutory basis for its measurement infrastructure, often in the form of legislation with the responsibility taken by one or more government departments, such as the Department of Trade and Industry (DTI)[2] in the UK, with such governmental organisations in most countries also providing direct funding to the National Measurement System (NMS). Moreover, the measurement infrastructure is presented at three different levels. Figure 1.1 (Spencer and Williams, 2002) shows the key features of measurement infrastructure following the top-bottom line. At the top is the National Measurement System, which contains the National Primary Metrology Institutes, National Accreditation Agencies and Legal Metrology Agencies. At the middle level are intermediate producers and service providers such as accredited and non-accredited calibration and testing laboratories and instrument makers. At the low level are the measurement users groups including industrial companies, public authorities and consumers.

As the main component of measurement infrastructure, the National Measurement System plays a crucial role in supporting the consistency of use measurement both in industry and society. In particular the National Primary Metrology Institutes (PMIs) which include four main components, National Physical Laboratory (NPL); National Engineering Laboratory (TUV NEL Ltd); Laboratory of the Government Chemist (LGC) and National Weights and Measures Laboratory (NWML) function as the top layer of measurement infrastructures; they sit at the key position of the National Measurement System. They carry out a range of activities from high science metrology to maintenance of reference materials as primary or national standards. Some PMIs are owned by governments and receive government funding directly; others are wholly private or semi-private meaning that part or all of their revenues need to be collected from commercial activities. According to Spencer and Williams (2002), in the EU on average around 64% of the PMIs funding comes from Member State governments, 26% from commercial activity.

[2] In July 2007, the Department of Trade and Industry was divided into the Department for Business Enterprise and Regulatory Reform (BERR) and the Department for Innovation, Universities and Skills (DIUS).



The measurement instrument makers are involved in metrology and the development of measures and provide important measurement equipment for the industry. They, together with other intermediate groups, play a vital role in connecting the NMS with final measurement consumers in the production process and by providing an important interface between science and industry. Although the measurement organisations or user groups can be categorized as shown in the figure based on their role or function, they are not operating independently. Indeed the interactions among them have resulted in difficulties in quantifying and distinguishing the effects of measurement separately.

In summary, much metrology and measurement which is embodied in instruments innovation and the diffusion of measurement technology occurs through the activities of National Standards Bodies, such as BSI. The evidence from Spencer and Williams' (2002) survey shows that in Europe alone each year €83bn or nearly 1% of EU's GDP has been spent on measurement activity from directly quantifiable sources. Industry production and trade in measurement and testing equipment within the EU is about €49bn per year, or approximately 1% of total EU industrial output. As for the benefits, this study shows that measurement delivers a significant impact of about 0.8% of the UK's GDP; net trade of measurement and testing equipment was around £1.2bn in 1999 in the UK economy as a whole (Spencer and Williams, 2002).

The chapter concludes by examining two important ways in which measurement activity can be evaluated and which are important in the empirical analysis of trade that follows in this thesis. The first is the key role played by instrumentation, since the development of increasingly sophisticated instrumentation has been regarded as a crucial channel that contributes to the tremendous advances in measurement science. In particular for the measurement and testing industry which provide the vital indicator to reveal the benefits derived by measurement activity. Therefore, the study employs the proxy of measurement instrument consumption, which calculates for the measurement and testing industry at each EU country. The second is the role played by technical standards in providing a codified source of knowledge concerning measurement techniques. Measurement infrastructure congregates codified knowledge and creates spillovers that are available across different sectors of the economy. Standards play the key role for the acceleration of knowledge diffusion. Thus the total standards stock has been considered as the important proxy to imply the comparative advantages and then dominant the trade flows.

1.3 Integrating Measurement into the Theory of International Trade

The purpose of Chapter 3 is to examine how measurement activity can be integrated into the theory of international trade. It is divided into two main parts. The first part argues that the standard Heckscher-Ohlin model is of little value and, consequently, any developments based on, as well as empirical works inspired by, the model are ignored and that recourse must be had to theories which have given technology a central role in explaining trade patterns. A number of empirical works in this area are also reviewed. The second part firstly provides a literature review of the relationship between measurement technology and international trade and then brings up the key hypothesis of the thesis - does the measurement infrastructure result in product differentiation which then promotes intra-industry trade?

From the point of view of the current thesis it is argued that the monopolistic competition approach to trade is the most useful. Monopolistic competition refers to a market structure that is a cross between the two extremes of perfect competition and monopoly. In other words it not only allows for the presence of increasing returns to scale in production and for differentiated products, but also retains many features of perfect competition, such as the presence of many firms in the industry and the likelihood that free entry and exit of firms in response to profit would eliminate economic profit among the firms. As a result, the monopolistic competition model offers a somewhat more realistic depiction of many common economic markets. Moreover, the scale of economies and product differentiation are two important characteristics of the monopolistic competition model and are especially useful in explaining the motivation for intra-industry trade.

Krugman pioneered the 'New Trade Theory' attempts to explain intra-industry trade in the late 1970s, which showed that the economies of scale, product differentiation and monopolistic competition are the main characteristics to explain intra-industry trade. The theory was developed further by Lawrence and Spiller (1983) who introduced factor endowment in this genre which made the model more economic reality. Based on this framework, the theoretical model of this thesis has been set up in chapter 4 and examines the effects of measurement infrastructure on the intra-industry trade in the UK by a monopolistic competition market. The model employed is that of a two-sector general equilibrium model where one sector is competitive and the other is monopolistically competitive. The most important feature of the model is the public good element to the costs of product differentiation. Arguably this public good effect is supplied by the measurement infrastructure. The model predicts that along with the impact of measurement infrastructure increasing, product diversity also increases, and then raises intra-industry trade between two equally endowment countries.

1.4 Measurement and Bi-lateral Intra-Industry Trade in the EU

The remaining chapters of the thesis are concerned with the empirical analysis of trade flows. The core objective of Chapter 5 is to examine the effect of measurement infrastructure on the extent of bilateral intra-industry trade between 14 EU countries and try to answer questions such as: to what extent is there evidence of differences in the measurement infrastructure between members of the EU? And to what extent can our empirical measures of the size of this infrastructure between industries explain differences in the extent of the variation in intra-industry trade between the different industries?

Due to the difference of historical development and economic structure, measurement infrastructures across Europe originally varied widely. The selection of the proxy to reflect measurement's involvement in international trade for a specific country is critical. Data from Spencer and Williams' report (2002) in terms of production, sales and trade in the EU measurement and testing industry has been used to calculate the total measurement instrument consumption for each EU country. The study then assumes that the data can be served as a proxy to represent a country's competitive advantage arising from measurement against its partner countries.

The econometric models of intra-industry trade focused on industry and country characteristics are tested with disaggregate data at the EU level for the year 1998. Apart from industry and country characteristics factors to be estimated, two variables related to measurements have also been considered, namely measurement standard intensity and average aggregate intensity of measurement instrument consumption. A number of options have been examined by using cross-sectional regression analysis. The empirical result shows that measurement instrument consumption has positive and statistically significant impacts on the intra-industry trade, which implies that measurement infrastructure plays a key role in determining the specialisation of a nation's, as well as the EU's, trade flows.

1.5 Measurement, Standards and the Pattern of Trade in UK Manufacturing

Chapters 4 and 5 focus on intra-industry trade. However, there is no reason why measurement should not also create a pattern of comparative advantage between countries. For example, the strength of the measurement infrastructure across industries may give the EU as a whole a pattern of specialisation at least partly based upon the extent to which industry uses measurement. Accordingly, chapter 6 switches emphasis, investigating the impact of measurement standards on the pattern of specialisation in UK manufacturing trade between 1993 and 2002. Three dependent variables, the export-sales ratio, import-sales ratio and export-import ratio are examined in order to capture the long-run pattern of trade specialisation. Having uncovered the long-run pattern of trade, a framework suggested by a multi-factor version of the Heckscher-Ohlin model of international trade, supplemented by a measure of standards across industries, is used to explain the results.

First of all, the analysis suggests that there is a strong statistical association between the standards made available by the British Standards Institution across 73 UK industries and the pattern of exports and imports is consistent with the trade promoting impact of standards. No additional impact is however found from measurement, which was tested using the extent to which an industry uses instruments. The export-import ratio provides a measure of comparative advantage. Because however, standard intensity is associated more strongly with UK imports than exports, standard intensity is therefore also associated with a slight comparative disadvantage. On the other hand, the evidence suggests that the UK has a comparative advantage in industries which have higher relative wages. This is consistent with the UK having a comparative advantage in products which are intensive in the use of human capital.

Chapter 2

The Economic Role of Measurement

2.1 Introduction

It is difficult to ignore measurement activities in our daily life. From a high precision CMOS chip, the scales at the supermarket checkouts, to the ride comfort of a train journey or a long haul flight. However, one of the most important functions of measurement may be overlooked by us, that is, the role of measurement and the science of metrology as essential support for state-of-the-art R&D which is the extremely sophisticated pre-requisite for technological innovation. In the UK, many scientific measurement activities are carried out by what is commonly referred to as the National Measurement System (NMS), directly supported by the Department for Innovation, Universities and Skills (DIUS) in the United Kingdom. The aim of this chapter is to investigate the rationale for the NMS – its economic role of the NMS, and the economic benefits it brings. Accordingly, this chapter is divided into five main parts: an overview of the whole chapter is presented here in the introduction, while the next section provides an introduction to the idea of the measurement infrastructure; a review of the economics of measurement follows in section 3. After that, the empirical evidence of the economic impact of measurement will be reviewed. The final section considers how measurement activities can be quantified for the purpose of the empirical analysis of international trade in chapters 5 and 6.

Section two briefly introduces the concept of the measurement infrastructure, highlighting where measurement takes place in the economy before examining the institutional structure of the NMS, the scientific measurement activities and programmes conducted by the NMS.

Section three examines the economics of measurement from four perspectives: namely the concept of infra-technology; the main measurement activities in an economy; the concept of common knowledge pools and the economics of standards.

Tassey (1990) defines infra-technology as knowledge regarding practices and techniques, basic data, measurement methods, test methods, and measurement-related concepts which increase the productivity or efficiency of each phase of the R&D, production, and the market development stages of economic activity. Infra-technology provides the knowledge base for the technology infrastructure more generally and has the characteristic that the knowledge of which it comprises depreciates slowly, but on the other hand requires considerable effort and long lead times to put in place and maintain. Jeffrey (2007) - the Director of the National Institute of Standards and Technology[3] (NIST, U.S.) - emphasized that "infra-technology" is part of the foundation upon which innovation is built. Also, "infra-technology" can be thought of as the roads, bridges, and communications networks of the scientific world. Similar to physical infrastructure, no one person or company can claim enough benefit from the work or has the capability to create this infrastructure. This "common good" infra-technology ultimately benefits whole industries (Jeffrey, 2007). In many industrialised nations, e.g., Japan, Germany and USA, the place of infra-technology has been recognised as part of economic policies to enhance competitiveness, and that the technology infrastructure needed to achieve a broadly competitive economy will increase in scope as well as depth in the next decade[4]. Moreover, recognizing the importance of "infra-technology" and NIST's role in innovation and competitiveness, the President of the United States, George W. Bush, has included NIST as part of the American Competitiveness Initiative[5] (ACI). The President's initiative includes key resources necessary for NIST to develop the measurement

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[3] National Institute of Standards and Technology (NIST) is the national measurement institution of the U.S.
[4] For example, refer to "1990 Science and Technology White Paper" by Japan's Science and Technology Agency.
[5] The American Competitiveness Initiative (ACI) is a federal assistance program intended to help America maintain its competitiveness Initiative (ACI) competitiveness through investment in research and development (R&D) and education (Wikipedia, 2008).

and standards tools to enable U.S. industry and science to maintain and enhance global competitiveness (Jeffrey, 2007).

According to Swann's (1999) report, the concept of a common knowledge pool – closely related to Tassey's concept of an infra-technology but applied more specifically to the role of measurement - will be discussed in the same section. The basic assumption of this model is that the generation of measurable product characteristics is closely aligned to the process of product innovation. One of the key mechanisms through which metrology and measurement related R&D become part of common knowledge pools in the form of accepted test procedures and agreed ways of measuring characteristics is through the publication and use of technical documents known as standards. The final part of this section investigates the economics of standards, reviewing types, functions and economic impacts.

Section four provides the literature review of empirical studies regarding the economic impact of measurement. Three main groups' studies have been reviewed. Those commissioned by DTI (United Kingdom), EC (European Commission) and NIST (United States) with others. In addition, an attempt to quantify the direct economic benefits of measurement with the aid of an economic model - Mapping Measurement Impact (MMI) - used in the UK's PA Consulting Report in1999 has been described in detail.

Since the object of this thesis is to study the relationship between measurement and international trade in the UK, section five considers the quantification of measurement activity for the empirical analysis of trade flows. The outputs of measurement activities and NMS have a considerable public good dimension which provides important benefits to the industry, and society as a whole. And standards with instrumentation can be viewed as two channels for knowledge transfer. Thus section five will mainly introduce the data of standards counts and instrument use by different industries and countries; importantly these figures can be viewed as two critical indicators to capture the characteristics of measurement activities.

2.2 The Measurement Infrastructure

2.2.1 Use of Measurement within the Economy

Many aspects of our daily life require accurate and reliable measurements, from a small flat pellet of medication to a new car, from commerce activities to scientific researches, from the automobile industry to the aerospace programme and so on. This section will briefly introduce where measurement activities take place in an economy - within industry, government and society as a whole.

Firstly, industry provides a demand for measurement activities. In general, industry uses measurement for quality assurance of goods and services, quality control in manufacturing, risk assessment and risk management, compliance with regulations, resolutions of disputes and complaints, and even for advertising data (Ticona and Frota, 2006). Take, for example, the EU automotives industry. It produced over 17 million automobiles in 2000 with a total turnover of around €321 billion (Spencer and Williams, 2002). This industry is heavily dependent on measurement activity, and at every stage, such as design, production pre-sales and so on. In particular, the process of automation requires accuracy in terms of component dimensions and in the positioning capabilities of automated, robotic assembly (Spencer and Williams, 2002). For the colour of each component which is manufactured at several different factories to be the same, this requires accurate measurement techniques and sophisticated instruments to ensure quality to meet safety, and other regulatory requirements and to reduce errors and component failure, such as certain well known car manufacturers, Mercedes Benz and BMW as an example. Therefore, it can be said that the more advanced and complex the technologies incorporated into a commercial product, the greater the need for measurement support.

Secondly, governments depend on the use of measurement for enforcement of or compliance with regulations, export/import controls and consumer protection, particularly for traffic control, medicine and health/safety management. The example highlighted here is that of the quality of food, one aspect of which belongs to the area of public health. Much of the measurement and testing related to food safety and public health are carried out by legal metrology organisations as directed by government and statute. Measurement and testing play a central role in diagnosing diseases such as the bovine spongiform encephalopathy (BSE), which had such a devastating effect on the British farming industry and UK agricultural exports. According to Spencer and Williams (2002) in year 2001, the target number of tests was raised from 130,000 to 170,000 per week, to ensure that the disease was properly monitored. Thus we can imagine that without proper measurement and testing in disease prevention and control there would be enormous potential damage not only to the economy but also to public health.

Finally, measurement plays a crucial role within the diversity of social activity. According to Spencer and Williams (2002), Europe's population was around 380 million in the year 2001, inseparable from measurement activity in the daily routines of shopping, travelling and business. For example, Europeans live in around 153 million households, and there are day-to-day uses of measurement such as electricity, gas and water as measured by domestic metering equipment. There is an average of one vehicle per household each needing to be tested on a regular basis for safety, road-worthiness and pollution emissions from the exhaust. At the petrol pump accurate and credible measurement is needed to ensure that customers are being treated fairly.

Health care is one of the largest areas of social use of measurement activities. There are more than 800,000 practising medical doctors and around 1.6 million practising nurses undertaking general medical testing such as blood samples or blood pressure tests almost everyday for clinical analysis. In addition, apart from such general medical testing, there are specific areas of public health concern such as cancer testing. HIV/AIDS testing and drugs dependence have an even higher demand for measurement and testing activities. Moreover, there are still many aspects of society where measurement holds an extremely important position. As Spencer and Williams conclude, the role of measurement and testing in society is substantial and is considerably greater than just its use in industry.

Therefore, we can perhaps draw the conclusion that measurement activity is widespread and indeed ubiquitous. It benefits industry, public health and security, environment protection, and thus society as a whole. Beyond the routine role of measurement, measurement plays an important role in the complex process of technological change and the generation of product variety which is the main consideration of this thesis. In order to understand that role in more depth, it is important to consider the part played by what is sometimes referred to as the

National Measurement System (NMS). This is discussed in the next section within the context of the UK.

2.2.2 The Institutional Structure of Measurement in the UK

The UK National Measurement System (NMS)

A suitable starting point for a consideration of the role of measurement in a modern economy is the concept of the national measurement system (NMS). In the 1989 UK White Paper *Measuring up to the Competition*, the NMS was defined as the technical and organizational infrastructure that ensures a consistent and internationally recognized basis for measurement in the UK. To achieve the ends detailed in the White Paper, the measurement infrastructure in the UK included several facets, or areas of responsibility. Birch (2003) described the measurement infrastructure as including the following:

- the International System of units of physical quantities (SI)[6];
- the National Measurement Institutes (NMIs) that maintain and develop the national standards of measurement;
- the calibration laboratories that maintain the traceability path and the laboratory accreditation organizations;
- the pattern approval testing laboratories, the measurement legislation and the enforcement of these measurement regulations; and
- the scientific and technical committees that develop international measurement standards and recommendations.

In the UK, these elements of the National Measurement System (NMS) can be thought of in terms of a hierarchy as illustrated in Figure 2.1 (adapted from Temple and Williams (2002b)). At the top level are the National Primary Metrology Institutes (PMIs), and intermediate are the accreditation and testing services such as testing organisations, calibration organisations and instrument makers. At the bottom level are the industrial and consumer sectors.

[6] This system is directed by the General Conference on Weights and Measures (CGPM) and maintained on a day to day basis by the International Bureau of Weights and Measures (BIPM) at Sevres, Paris.

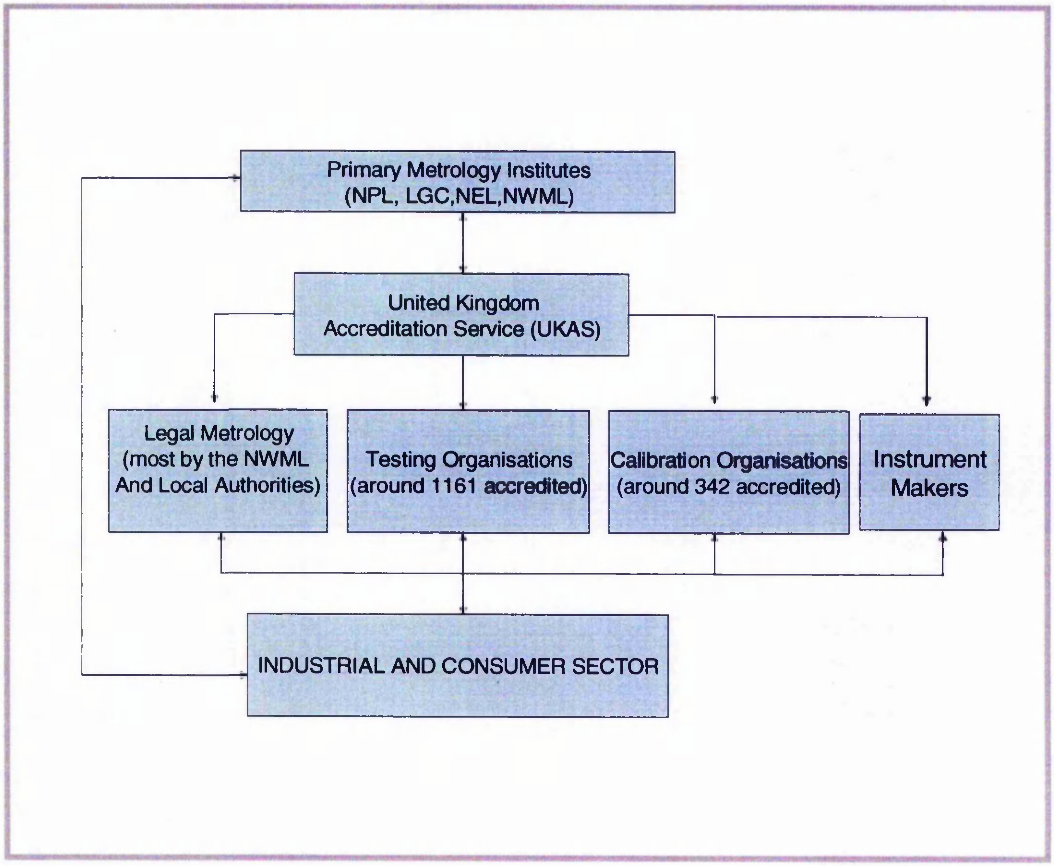

Figure 2.1 The United Kingdom National Measurement System

(Source: Temple and Williams, 2002b)

The National Primary Metrology Institutes (PMIs) in the UK comprises four main bodies:

- The National Physical Laboratory (NPL) which focuses on physical metrology;
- The National Engineering Laboratory (TUV NEL Ltd) which is responsible for the management of the Flow Programme;
- The Laboratory of the Government Chemist (LGC) which concentrates on chemical and biological metrology;
- The National Weights and Measures Laboratory (NWML) which services legal metrology in the UK by providing a range of calibration services centred on the trading parameters of mass, length, and volume etc.

Ownership differs between the institutions: today, the LGC and NEL are fully privatized companies, while NPL is run under contract to the DIUS by NPL Management Limited (Bowns *et al.,* 2003)[7].

The National Primary Metrology Institutes (PMIs) in the UK are responsible for the realisation and distribution of internationally agreed measurement units and standards at the level of precision required by users and forms an important part of the science base (Temple and Williams, 2002b).

An idea of the nature of the linkages between the PMIs and the science base can be seen by looking at spending patterns. The distribution of PMIs' spending by generic activity is shown in Table 2.1. Research into technologies to obtain and develop new NMS standards and developments and improvements to the existing NMS suite of standards account for the highest part of the funding (23% each). Maintenance activities[8] are almost as important (20%). By contrast, regulation and the international liaison both take up smaller parts of measurement activities - at 3% and 5% respectively. It should be noted that these activities help the PMIs provide an intermediary role between the advances of science and metrology to perceived areas of development of industrial, scientific and regulatory areas. Of course, whether these areas are actually of significance is the object of various reviews.

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[7] NPL Management Ltd. is a wholly owned subsidiary of the Serco Group; however the DIUS retains ownership of NPL land and buildings and major items of scientific equipment.

[8] Maintenance activities may involve fundamental research which supports the measurement infrastructure, as well as maintaining the existing NMS suite of standards to the level required by users, etc.(PA Consulting Report,1999).

Activity	Description	Share of budget (%)
Research	New technologies and standards	23
Development	Developments and improvements to the existing NMS suite of standards	23
Maintenance	Maintaining existing standard reference measures	20
Dissemination	Technology transfer programmes and initiative	14
International traceability	Establishing and maintaining international comparability of standards	6
Regulation	Contributing to legal metrology applications	3
Management	Project management and delivery	6
International liaison	Standards bodies such as EUROMET	5

Table 2.1 The Distribution of Primary Metrology Institutes Spending by Generic Activity

(Source: PA Consulting Report, 1999)

The distribution of staff by function also illustrates the significance of the PMIs for the science base. These are summarised in Table 2.2. It shows that scientists and engineers take up a higher proportion of staff in PMIs than other types, accounting for 64.4%; this proportion is followed by other administrative staff (22.7%).

	%	Number
Scientists and engineers	64.4	539
Technicians	4.5	38
Managers	6.9	58
Other administrative staff	22.7	190
PhD students	1.5	13
Other	0	0
Total	100	837

Table 2.2 Staff Levels in Primary Metrology Institutes in the UK

(Source: Spencer and Williams, 2002)

Significant public resources are used to support the PMIs, but there are important differences between the UK and other EU countries. The comparison of total income of PMIs with the EU is shown in Figure 2.2. It shows that the total income of NMIs in Germany is the biggest, followed by the UK, Sweden and France. In terms of income sources, Table 2.3 below shows that although core government funding of the UK is relatively lower than other EU countries, commercial activity (including government tenders) run by PMIs is much higher than the others. Table 2.3 also shows how the total income is derived from several subcategories, namely, core government funding, the EU, commercial activities, industrial partnerships and other approaches. Indeed, the structure and function of NMIs varies significantly across EU countries, and the income source for each country represents its own characteristics, as show in Appendix 2.1. It can be seen that for the centralised systems such as Portugal or Sweden, the income from private sources are 90% and 82% respectively. Nonetheless, in Germany private activity is also relatively small, as 90% of funding comes from public sources. For the EU as a whole, the distribution is 64% public, 26% commercial, 7% EU sources and 3% industrial partnerships.

Income	**%**	**€million**
Core government funding	47.9	66.6
European Union	2.4	3.4
Commercial activity(including government tenders)	47.5	66.1
Industrial partnerships	2.2	3.1
Total	100	139.2

Table 2.3 Funding of Primary Metrology Institutes in the UK

(Source: Spencer and Williams, 2002)

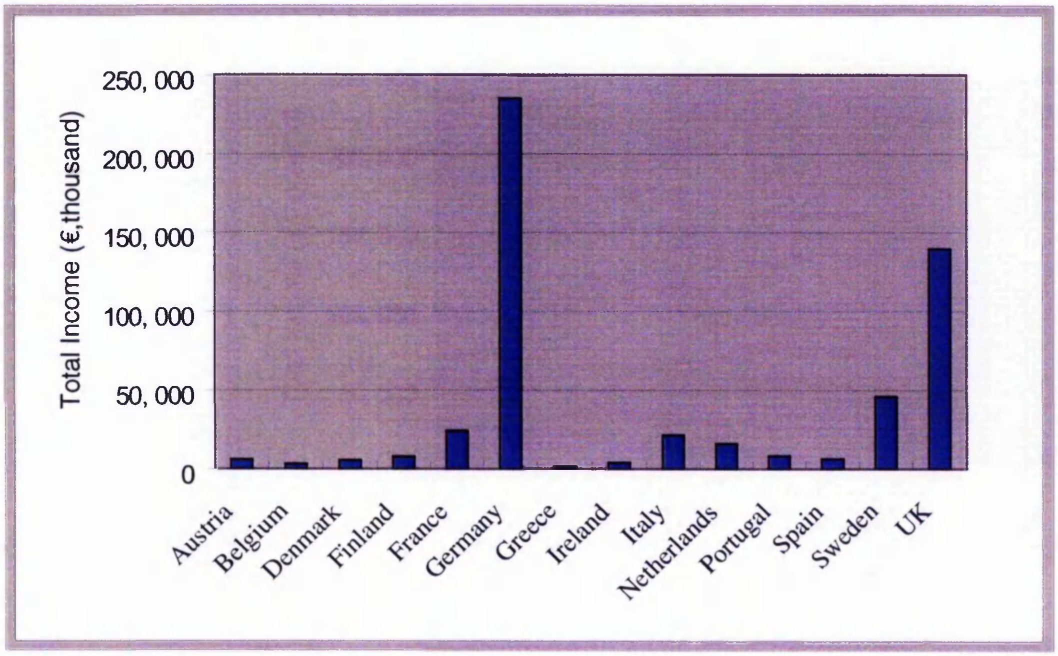

Figure 2.2 Comparison of Total Income of NMIs in the EU

(Source: Spencer and Williams, 2002)[9]

The UK's total public budget for the National Measurement System (NMS) was around £60 million in year 2003 (UKNMS Measurement Advisory Committee Final Report, 2006). Due to tighter public expenditure constraints at the time, resources devoted to the UK NMS have been reduced during the last decade (from mid-1990s until nowadays). However, there has been a gradual increase in income from other sources, mostly public private partnerships and commercial activities.

Of course many of the types of commercial measurement activities such as calibration services derived from their specialized equipment, workshops, etc., performed by the PMIs are performed on a much larger scale by a diffuse network of private calibration, testing and inspection organizations, which also therefore form an important part of the technology infrastructure in the private sector. Arguably however, the specific types of calibration, testing, etc., reflect the particular specialized equipment and skills obtained through the research undertaken. Many of these private sector firms receive formal validation from the

[9] The data sources for Figure 2.2 referred in Spencer and Williams' report (2002) are taken from Survey of NMIs. Data for Luxemburg is not available.

United Kingdom Accreditation Service (UKAS) which is recognized by the UK Government as the sole accreditation body for conformity to international standards in the management of measurement procedures, e.g., ISO 9000 and EU45000 [10] (Temple and Williams, 2002b).

Calibration and testing laboratories, particularly those accredited by UKAS, play a vital part in the NMS. According to the study by Temple and Williams (2002b), in year 1999, UKAS provided accreditation to around 342 calibration laboratories and 1161 testing bodies, 92 certification organizations and 81 inspection and verification bodies. UKAS employed core staff of around 106 people with an additional 300 technical assessors. The total turnover was around £8.3 million with sales of £5.4 million. Laboratory accreditation accounted for 71%, certification body accreditation 14% and inspection bodies 5%. The remainder accrued from training and publication sales. In addition, the calibration laboratories issued around 600 000 UKAS calibration certificates in 1999, mostly to Small and Medium Sized Enterprises (SMEs). Spencer and Williams (2002) suggest that a lower bound for the costs to industry from accredited calibration organizations alone would be around £360 million (Temple and Williams, 2002b). Therefore, it seems that the UKAS credited laboratories not only constitute the main channel for the dissemination of measurement standards but also provide an important service to a wide range of customers in British industry. Figure 2.3 shows the distribution of accredited calibration laboratories by type. There are clear concentrations in mechanical and dimensional quantities used mainly in manufacturing and in electrical measurement.

[10] The ISO 9000 series for overall management systems introduced in 1987; the EU 45000 series for testing, calibration and accreditation introduced in 1989 (PA Report, 1999).

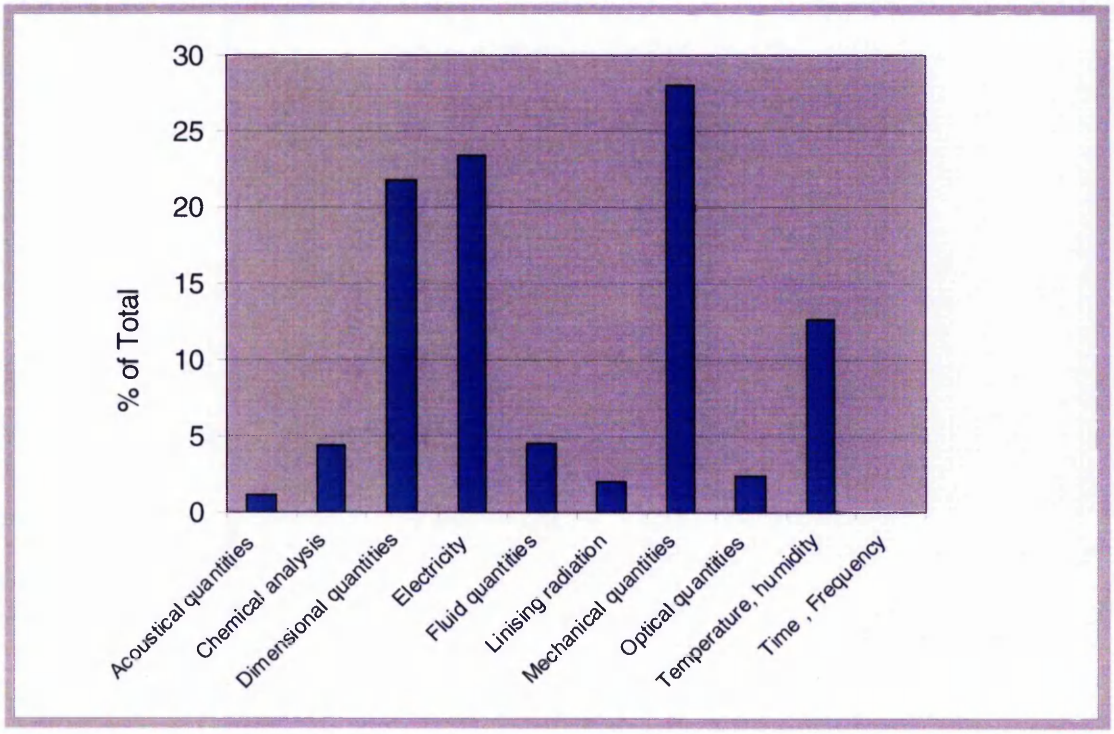

Figure 2.3 The Distribution of Accredited Calibration Laboratories by Type

(Source: Spencer and Williams, 2002)

Research and Other Programmes of the NMS

The Department for Innovation, Universities and Skills (DIUS) is responsible for the publicly funded element of research activity of the NMS through the NMS's investment in measurement science and technology programmes. Each programme contains a mix of activities, loosely classified into three main categories, i.e., maintenance of standards, R&D and Knowledge Transfer. In general, each programme runs on a three-year cycle and contains any number of projects that have possible applications in a wide range of industrial sectors (Rushworth[11], 2005). Knowledge transfer activities play a vital part of each individual project. In addition, half way through each programme, the formulation of the next programme will be initiated. Meanwhile, the number of programmes and the number of individual projects vary between funding rounds. Currently, there are 21 technology programmes areas funded by DIUS and those conducted by the UK PMIs are shown in Figure 2.4.

[11] Jessica Rushworth is part of the directorate of National Measurement System, DIUS.UK.

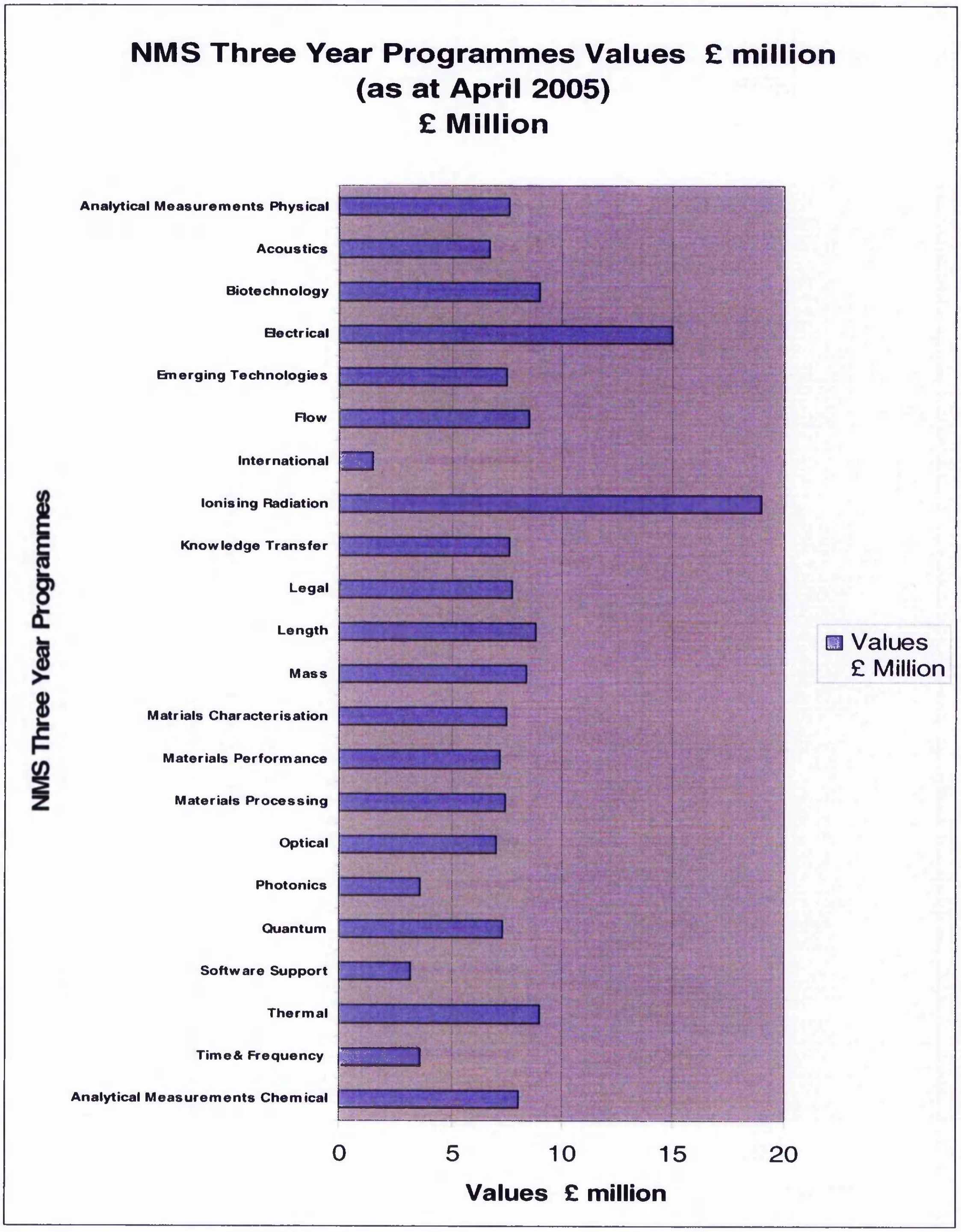

Figure 2.4 National Measurement System Programmes

(Source: Rushworth, 2005)

Figure 2.4 clearly shows that the Ionising Radiation Programme accounts for the highest proportion of the budget - around £19 million - followed by the Electrical program at £15 million. The programmes of Thermal and Biotechnology are about £9 million respectively, and for Length, Flow, Mass and Analytical Measurements Chemical programmes are over £8 million. There are also many others, serving once again to illustrate the diversity of measurement activity. However, according to the report of the strategic review of the UK NMS which was conducted by DTI (2006), these programmes can be roughly divided into 5 categories[12], based on:

- International System (SI) of units - seven programmes (Length, Mass, Thermal, Time and Frequency, Optical , Electrical and Valid Analytical Measurement);
- Derived units - two programmes (Acoustics and Ionising Radiation);
- Market sectors or technologies - seven programmes (Measurement for Biotechnology, Photonics, Flow, MET and 3 Materials programmes -Characterisation, Performance and Processability);
- Fundamental underpinning research - two programmes (Quantum and Software Support); and
- Crosscutting services - two programmes (Knowledge Transfer and International Metrology).

Due to the present NMS portfolio of programmes, in a recent report Rushworth (2005) argues that emphasis in the future should be sub-divided into two main types, 'Knowledge Base' and 'Metrology R&D', characterised by their intended impact. As indicated in Figure 2.5, Knowledge Base includes five programmes, provisionally called Chemical and Biological Metrology, Engineering and Flow Metrology, Ionising Radiation Metrology, Materials and Thermal Metrology and Physical Metrology. And for the Metrology R&D within the provisionally named Metrology for advanced Manufacturing and Information and Communication Technologies (ICT), Metrology for Healthcare and Security and Metrology for Transport, Energy and Environment, and based on the current Technology Strategy priorities. For the two main programme areas she recommends the creation of two cost cutting strategic NMS programmes comprising an International programme and an NMS

[12] Excluding Legal Metrology.

Portfolio Knowledge Transfer programme. Furthermore, in order to adjunct to the five Knowledge Base programmes, she suggested two underpinning programmes, comprising Software Support for Metrology and Quantum Metrology that pick up and satisfy the requirements of the Knowledge Base programmes in these fields.

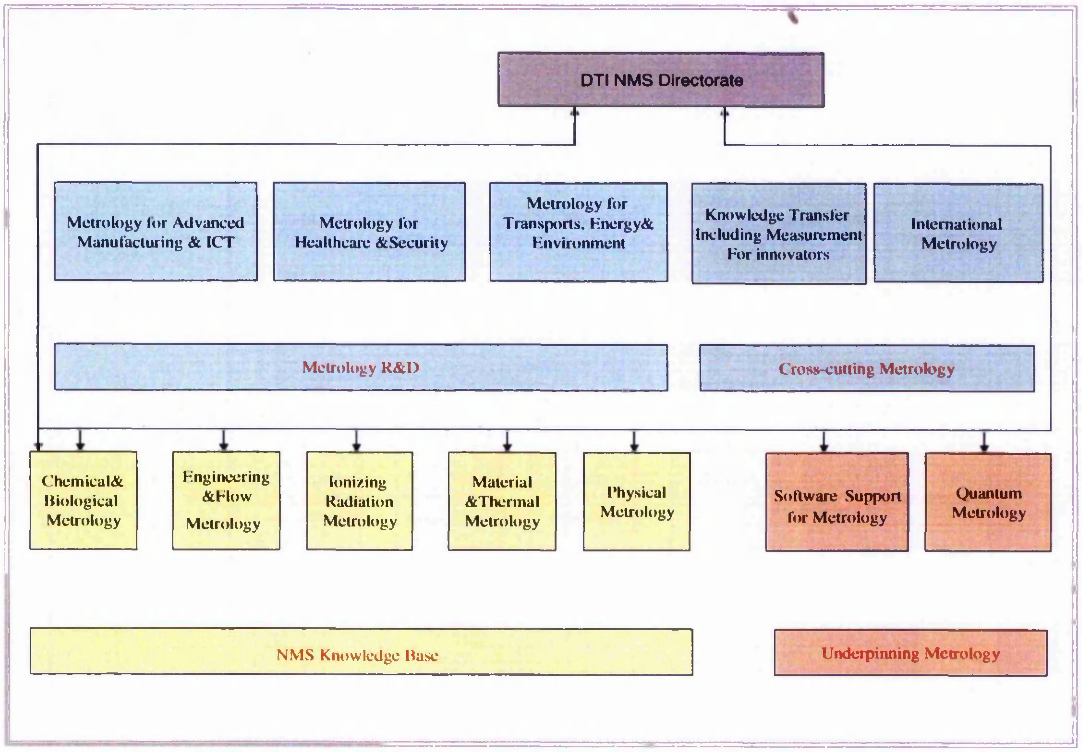

Figure 2.5 The Structure of NMS Programme Portfolio

(Source: The Strategic Review of the UK National Measurement System, DTI, 2006)

These programmes are therefore mainly concentrated on providing state of the art technology and measurement. It is useful however to focus on one particular example, and an illustrative example of the Flow Programme is given in Appendix 2.2, showing its impact on UK economy and industry.

Introduction of Standards

According to *Metrology-in short,* the report provided by European Collaboration in Measurement Standards (EUROMET, 2003), measurement as an essential scientific activity generally contains three main steps. The first is to define the units of measurement that can be implemented in the nation, and that they are recognized and accepted by international organizations. The second is the realization of units of measurement by scientific methods. The final step is the establishment of traceability chains[13] that allow for the determination and documentation of the accuracy of a measurement and the dissemination of that knowledge. It can be argued that this final step is the most important; this not only creates measurement standards but also elicits another important measurement activity - calibration - which uses accurate instrumentation as a key tool allowing for comparison against standards. Standards are documented, providing a key mechanism to ensure that products and services are fit for their purpose and are comparable and compatible (David and Steinmueller, 1994). Thus before we discuss the economic impact of standards in later chapters, we first give a brief introduction to the definition of industrial standards.

Clarke (2004) defines a standard in general terms as an agreed way of doing something. Industrial standards share this definition since they represent an agreed set of technical specifications. These types of standards can be recorded and published formally, or simply be informal unwritten procedures that a company uses to maintain efficiency or gain another advantage. A formal standard can then be defined as:

'a document established by consensus and approved by a recognized body, that provides, for common and repeated use, rules, guidelines or characteristics for activities or their results, aimed at the achievement of the optimum degree of order in a given context.'

Source: ISO/IEC Guide 2, CEN, 2002.

The World Trade Organization (WTO) defines a standard in a little more detail:

'A document approved by a recognized body that provides, for common and repeated use, rules, guidelines or characteristics for products or related processes and production methods, with which compliance is not mandatory. It may also include or deal exclusively with terminology, symbols, packaging, marking or labelling requirements as they apply to a product, process or production method.'

The WTO, Agriculture and Sustainable Development, 2002, p128.

[13] The traceability chain is the chain along which measures can be compared and from which the accuracy of measures can be judged (Williams, 2002).

In the parlance of modern technology therefore, a 'standard' (taken in this thesis to mean an industrial or technical standard) is understood to be a set of technical specifications that can be adhered to by a producer, either tacitly, or in according with formal agreement, or in conformity with an explicit regulatory authority (David and Steinmueller, 1994). They may emerge through purely market processes (so called '*ad hoc*' standards as in those created by Microsoft or the Ford Motor Company) or through the deliberations of the technical committees of specially constituted bodies, such as the British Standards Institution (BSI) in the UK, which are frequently national in character. Many standards, as we shall see later, refer to ways of measuring performance characteristics and hence represent an important means by which metrology and measurement more generally become part of a common-knowledge pool.

2.3 The Economics of Measurement

The preceding discussion has established the coherence and relevance of a set of activities based around measurement in a modern economy. The relevance of a specific economics of measurement in the context of this thesis stems from the significant part played by measurement in the process of technological change. The widespread and growing interest in technological change more generally, but particularly among both policy makers and economists, stems not only from the fact that it is not only now recognised as a major contributor to economic growth (Nelson, 1995; Fagerberg, 2000; Verspagen, 2001), but because the process of technological change is subject to all three commonly recognised 'generic' types of market failure (e.g. Geroski,1995) – externalities, indivisibilities and uncertainty.

Externalities, as the first source of market failure, occur whenever there are costs or benefits to a particular activity that are not fully reflected in market prices. Externalities may be both positive and negative in character. In the context of technological change, the type of externality most frequently analysed is that of the technology (or knowledge) 'spillover' in which the ideas incorporated in an innovation are imitated, reducing or even eliminating the returns from the resources invested by the innovator. In this context, markets may not provide the right incentives to produce.

The issue related to spillovers is one of excludability, i.e., the possibility that others besides the innovator cannot be excluded from benefiting. In these circumstances, firms will develop strategies enabling greater excludability. In the case of technology the most obvious of these is the use of secrecy, 'lead times' or vertical integration (Geroski, 1995). General belief in the lack of an incentive to innovate of course has led governments to try and protect intellectual property by creating temporary monopoly rights via the patent system. The famous 'Yale studies'(Levin et al., 1987) into the appropriability of R&D investments showed that in many industries secrecy and lead times were more important as a means of protecting intellectual property than the patent system.

Knowledge itself is sometimes held to have the property of a public good. Public goods may be thought of as an extreme type of externality where excludability is impossible or at least prohibitively costly. There are in fact two principal characteristics of public goods, one is non-rivalness in consumption: the consumption of the good by one person does not prevent its rivalrous consumption by another person; there is thus a potential for collective consumption. Another way to define non-rivalness is to say that a good is non-rivalrous if for any given level of production, the marginal cost of providing it to an additional consumer is zero. This is clear in the case of measurement activities, for example measurement standards. One firm using a standard metre does not preclude its use by another; indeed the more firms who use a measurement standard the greater its utility to any one of them. In addition, another principal characteristic of a public good is non-excludability, in the sense that one person cannot exclude another person from consuming the good in question. Thus once the standard metre has been established and promulgated, it is virtually impossible to prevent anyone using it without payment. Something similar can be said of industrial standards – excludability may be difficult while at the same time the use of a standard through conformity in no way precludes its use by another.

The second generic source of market failure is indivisibilities. These arise where the costs of an activity have a significant fixed cost component which cannot be divided amongst those who would benefit. According to the study by Geroski (1995), the creation of new knowledge frequently involves large fixed set-up costs and such activities often requires the division of highly specialized labour. This is relevant for measurement activities. Since measurement technology is discrete, it cannot be sold in small units, thus marginal costs are generally driven below average costs, which make marginal cost pricing economically unviable.

Furthermore, there is a tendency towards monopolization of such markets. For example, accurate measurement is a key attribute of the mass assembly technologies associated with US manufacturing, the logic of which required a considerable scale of activities.

The third source of market failure is uncertainty. Investments in measurement activities involve two types of uncertainty: on top of technological uncertainty (how to achieve more accurate measurement standards and how to make them work), there is also – at least for product innovation - market uncertainty (how to make new measurement standards adopted by the consumers). The decision to invest in measurement is therefore necessarily mixed with decisions to bear risk, and below we see how Swann (1999) relates much measurement activity to investment decisions more generally. Separating the two types of decisions is often difficult because of moral hazard, which arises when the transfer of risk undermines the efficiency of the investment. The difference between product and process innovation may be important when it comes to discussing the role of standards and the measurement infrastructure more generally since the common pool may be especially important in reducing market risk.

Because of these three sources of market failure, there is room for government intervention in relation to technology. As suggested in the PA Report (1999) government intervention may include some or all of the following strategies: direct provision of the activity by the government; provision of an enabling framework to support the activity and provision of a regulatory framework to require private provision of the activity. We saw in the last section that the measurement and standards infrastructure contains elements of all three types of intervention.

The following section considers the economics of measurement more specifically. The first considers the relationship of measurement to technology, using the concept of infra-technology - shared tools and knowledge which enable innovation and the development of markets. The section then turns to a discussion of the three main measurement activities as emphasised by Swann (1999). Then, Swann's other important contribution, the "common knowledge pool" model, is discussed. Finally, because of their importance in enabling the measurement infrastructure to distribute benefits, the economics of standards is reviewed.

2.3.1 Measurement and Technology: the Concept of Infra-technology

In this section we consider how measurement fits into the more general technological framework of a market economy, building upon the pioneering work of Tassey and others in the U.S. This approach is built upon a consideration of how science is linked to market activities. Although the emphasis in their work is on the U.S., their approach remains an important way in which these linkages may be conceptualised.

Measurement has long been considered as an important area for scientific research, known as metrology. The science forms the basis for the development of measurement itself. In particular, metrology and measurement can be regarded as a form of 'underpinning' technology or a set of 'infra-technology' that supports other forms of activity such as production, innovation and marketing (Tassey, 1992). Infra-technology[14] consists of a set of tools that include measurement and testing infrastructures, industrial and commercial standards, reference materials[15] and databases that are used in science, engineering and production processes (Tassey, 1997). The infra-technology supplied by measurement is in this sense a fundamental technology, supporting the research and development, production and marketing activities of individual firms and industries. The term 'infra-technology' was first used by Tassey (1992) to describe the infrastructure technology that resulted from laboratory research. Subsequently it was adopted by a United States policy statement - the Economic Report of the President in 1994 (Coursey and Link, 1998).

In addition, according to Leyden and Link (1992), the science base provides the foundation for much of the new technology seen today. This base depends upon basic research that is funded primarily by the public sector. Basic research is the search for fundamental scientific principles without consideration of practical application. Since it does not consist of appropriable knowledge, incentives are lacking for full support by the private sector; at least half of all basic research is conducted at universities and governmental agencies (Leyden and Link, 1992).

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[14] Infra, as a prefix, means 'below'.

[15] Material or substance that one or more of whose property values are sufficiently homogenous and well established to be used for the calibration of an apparatus, the assessment of a measurement method, and for assigning values to materials (Metrology-in short, 2003).

As indicated in Figure 2.6 infra-technology may be thought of as one of the discrete elements of the 'technology infrastructure'[16], but one which is perhaps less widely recognized as part of an industry's technology base. However, this technology indeed provides a varied and critical technical infrastructure such as providing research methods and evaluated science and engineering databases to support the development of generic technology and subsequent actual market applications. The latter comprise the proprietary technology which creates competitive advantages for firms. Together with generic technology, infra-technology therefore provides linkages to the science base itself.

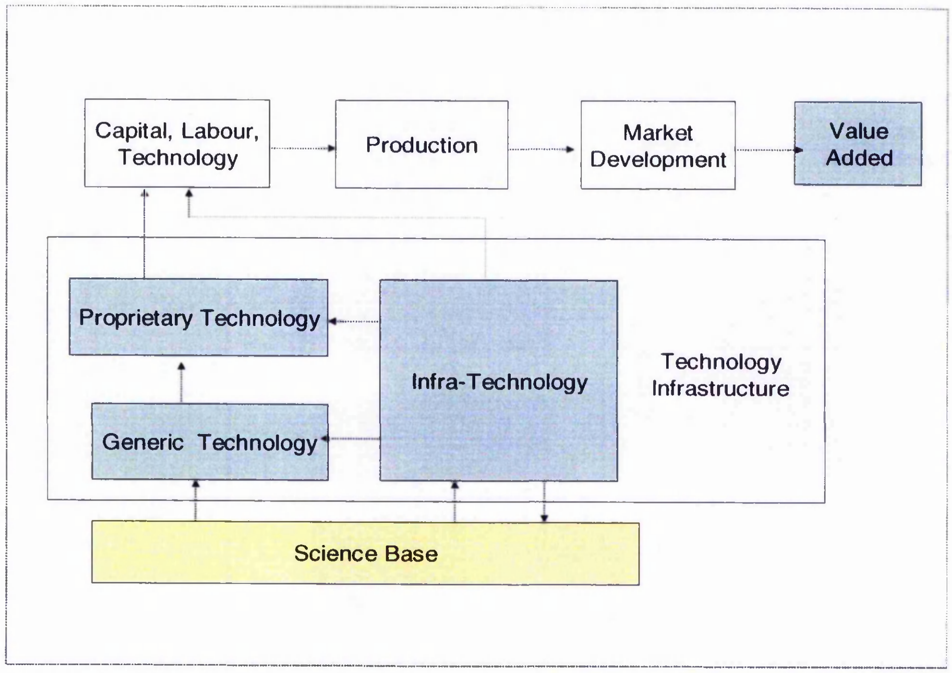

Figure 2.6 A Model of Technological Development

(Source: Leyden and Link, 1992)

Technology infrastructure consists of science, engineering and technical knowledge which has been defined as an element of an industry's technology that is jointly used by competing firms. Such knowledge can be embodied in human, institutional and facility forms. As described above, this advanced infrastructure includes three key technology elements: generic

[16] Tassey (1991, 1992 and 1995), Justman and Teubal (1995) and Teubal, Foray, Justman and Zuscovitch (1996) have developed taxonomies.

technology, proprietary technology and infra-technology. In general, generic technology is the first result of attempts to draw upon basic science for market application. They are the core product and process concepts from which specific commercial applications are developed through subsequent applied R&D (Tassey, 1997). Proprietary technology is so-called because it is appropriable by individual firms as long as they are protected in some way. Such product and process technology results from self-financed research or from development activities concerned with creating marketable technology based products or production processes. Most importantly, the shared elements of infra-technology may be thought of as consisting of a set of "technical tools" such as evaluated scientific data used in the conduct of R&D, measurement and test methods used in research, production control, and acceptance testing for market transactions; and various technical procedures such as those used in the calibration of equipment, fundamentally for making the entire economic process more efficient (Leyden and Link, 1992), in ways closely related to reductions in the costs of using the market, i.e., Coase-Williamson's the transactions costs.

Generic technology, proprietary technology and infra-technology are three interrelated elements of industrial technology as the arrows in Figure 2.6 suggest. Importantly, they are dependent upon the science base that is essential for the conduct of R&D and for the efficient production and utilization of the resulting technologies. In addition, Figure 2.6 also illustrates a simple linear view of an economic activity model (through dash lines), in which these three important technology elements and the science base support the technology inputs, with other factors of production-capital, labour, and together enter the production process, and an output results. Market conditions then give the product economic value. Meanwhile, it is worth stressing here that the technology infrastructure increases the emphasis on scientific measurement research and technological innovation (Tassey, 1997). Here measurement techniques play a prominent role as part of infra-technology as it is frequently requisite to technological innovation in their support of markets. It is this aspect that is crucial to understanding Swann's contribution discussed later.

The Categories of Infra-technology

Before proceeding to the detailed analysis of measurement activity it is useful to give a further discussion of infra-technology. This discussion is largely based on Leyden and Link (1992) and Tassey (1997).

As mentioned above, infra-technology is not generally embodied in an industry's product technology. Instead, infra-technology facilitates the development of generic technology by providing highly precise measurement and creating organized and evaluated scientific and engineering data necessary for understanding, characterizing and interpreting relevant research findings. Typically, Leyden and Link (1992) argue the fundamental units of measurement and also provide the measurement and testing concepts and techniques that enable higher quality and greater reliability at a lower production cost. Infra-technology also provides the technical basis for a number of types of standards such as those affecting process and quality control at the production stage and the efficiency of market transactions through the reduction of performance risk to the buyer of advanced products and services. Finally, infra-technology provides buyers and sellers with mutually acceptable, low-cost methods of assuring that specific performance levels are met when technologically sophisticated products enter the market place (Leyden and Link, 1992).

Tassey (1997) provide a useful classification of infra-technology, dividing it into four general categories:

- A scientific and engineering database;
- Measurement and test methods;
- Production practices and techniques[17] ;
- Interfaces permitting the efficient connection of components in manufacturing and service systems.

Two features of the above list stand out. First, much of infra-technology emerges from the science base as 'agreed' aspects of technology among market participants. This agreement has clear public good aspects which facilitate market transactions. Second, much of this agreement typically will take the form of so-called 'codified' knowledge and information. One important source of codified information which incorporates such knowledge is the stock of industrial standards – technical documents which specify processes, product characteristics,

[17] Such as process control models, that allow various elements of the typical industrial technology to be organized and utilized efficiently.

etc., and which frequently emerge in a process of voluntary cooperation between interested economic agents.

As far as economic impact is concerned, Tassey (1997) emphasises the role of infra-technology in influencing both static and dynamic efficiency. As Figure 2.7 indicates, these technical tools are ubiquitous in the technology-based economic growth process. They affect the efficiency of the triad of R&D, production and marketing. At the first stage, the R&D process requires a complex supporting infrastructure, including measurement methods and highly accurate science and engineering databases to first carry out R&D, replicate experiments to demonstrate or verify the initial results and then to communicate the research results effectively to those who authorize follow-on R&D funding and eventual commercialization. As for production, reducing unit production costs through higher yields, efficient material usage, and less down time are major objectives of new process technologies. Attaining this productivity goal while also achieving desired levels of quality and reliability requires real time process control as opposed to the traditional end of the line testing or inspection. In industries where product development is important, the acceptance of new products requires technologically sophisticated test equipment and procedures which are able to measure sometimes novel new characteristics. The cost of disagreements between buyers and sellers over performance can be substantial and adds to the cost of the product, thereby slowing market penetration. By facilitating communication between buyers and sellers, agreed test methods and measurements reduce transactions costs.

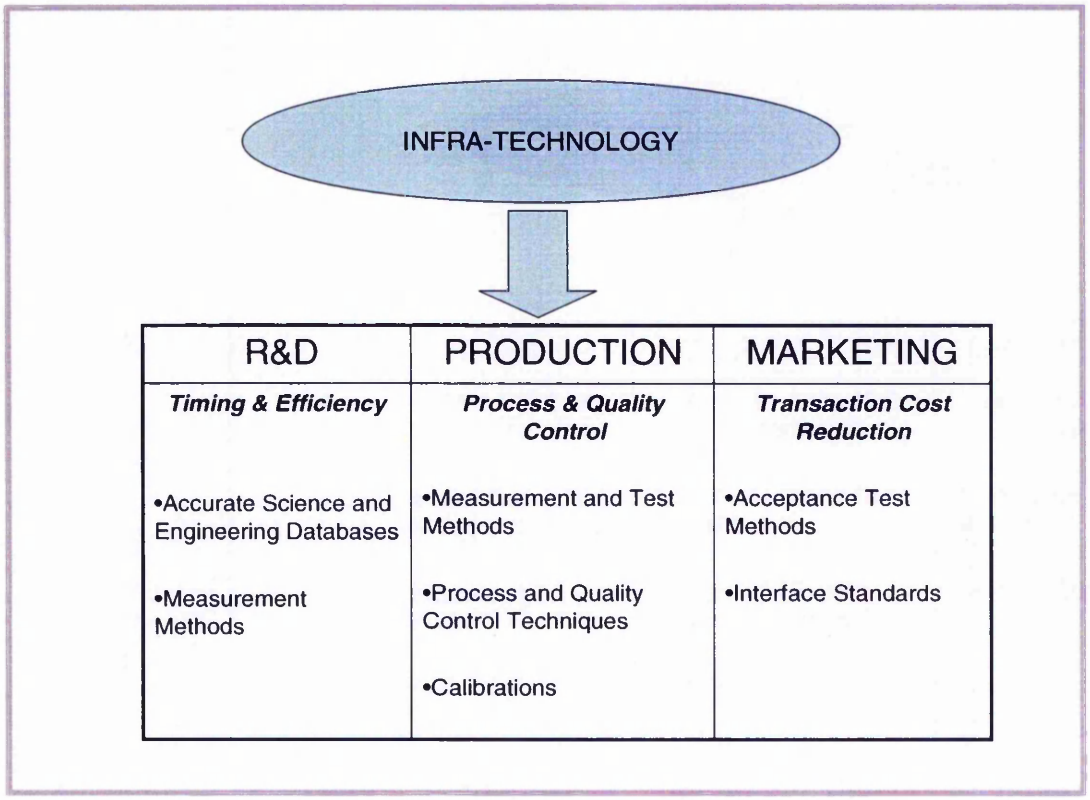

Figure 2.7 Types of Infra-technology by Stage of Economic Activity

(Source: Tassey, 1997)

To summarise, infra-technology therefore has similar characteristics to other technologies, in that they can lead to greater efficiency and higher productivity. They can be used for a variety of different purposes and complement other technological innovations in driving growth processes. On the other hand, a principal characteristic of infra-technology is the fact that they are shared and essentially non-appropriable, bearing many of the characteristics of public goods since – in addition – their use is frequently non-rivalrous. Infra-technology essentially facilitates communication between different economic agents and hence provides an important support for markets, especially in science and technology driven industries.

The public good aspect of measurement technology (and infra-technology in general) makes them of great interest for economic analysis. There is of course a presumption that public goods will be under-provided by the market. Moreover, the ways in which policies and institutions operate to correct this market failure are subject to considerable variety. Having used the concept of 'infra-technology' to help in the understanding of how certain measurement technologies are used, it is now important to survey and discuss the economic aspects of measurement activity in more detail. The two major sources used in this survey are the PA Consulting Report on the National Measurement System (1999) and Swann's *Economics of Measurement* (1999), both commissioned by the Department of Trade (DTI) in London.

2.3.2 The Economic Analysis of Measurement Activity

The previous sections considered the key institutions supporting measurement and the ways in which measurement forms part of the science base and provides linkages to appropriable technological activity. Economic activity involving measurement of course embraces much more than the institutions and agencies that form the National Measurement System and it is useful to consider how these different types of activity fit together in the case of the UK. In order to understand the economic role of measurement, Swann (1999) identified measurement as consisting of 3 types of activities, for which different types of economic analysis are appropriate:

- Research, embracing basic research, new techniques and the development of novel reference materials;
- Developing tools and infrastructure, containing method evaluation and development, reference material production and certification and fostering international compatibility and so on; and
- Using tools and techniques: real-world measurement, application of methodological principles and use of reference materials.

In the UK, these activities are located in both the public sector, such as the National Physical Laboratory (NPL), and private sector, such as small specialist analytical labs[18]. In general however, the extent of private sector involvement is higher as we move down the list.

[18] For example, home self-test medical kits.

Importantly, as Swann observes, the three different types of analysis are associated with different cost function which can be used to rank them according to ascending order: the largest fixed cost is research activity, and the type of research carried out at, say, NPL often involves equipment - but the knowledge generated here can be transferred at relatively low marginal cost. Developing new tools sits at the second tier .The lowest fixed cost is use of measurement for day to day purposes. Additionally it is possible to rank the three activities with the potential for market failure, especially for the research activities which require high fixed costs. Also when the results of research and developing tools and infrastructure can be used in a wide range of different industries; there are also important potential sources of market failure. An issue in the case of this second tier of activities which features in reviews of the NMS in the UK concerns the extent to which the public goods created in the development of infrastructure are in fact 'clubbable,' i.e. turned into a so-called 'club good' in which there are a few major beneficiaries who can be persuaded to pay for the good on the basis of a degree of excludability. An example might be privileged early access to metrological research results. Evidently, the more diffuse the benefits, the less this solution to market failure is possible (for further discussion see Swann 1999).

After describing these three main sorts of measurement activity, Swann (1999) created an 'economic map' that shows how measurement activities fit into the broader framework of a market economy. As seen in Figure 2.8, the box with capital letter M indicates measurement. Generally, measurement is located inside each organisation, such as the box of a producer or customer. Moreover, along with traded goods and services, it is part of the exchange between organisations. In addition, there are four types of measurement activities inside each measurement box, namely internal regulations (e.g., health and safety of its workers), external regulation that governs the effects of operations on the outside world (e.g., environmental pollution standards), operational measurements and measurement research and tools. Internal regulations are mandatory measurement activities that conform to regulations that govern operations within the company such as health and safety regulations; external regulations, for example, include environmental regulations. Operational measurement is part of the production process. Finally there are activities directed towards improving measurement tools and research (Swann, 1999).

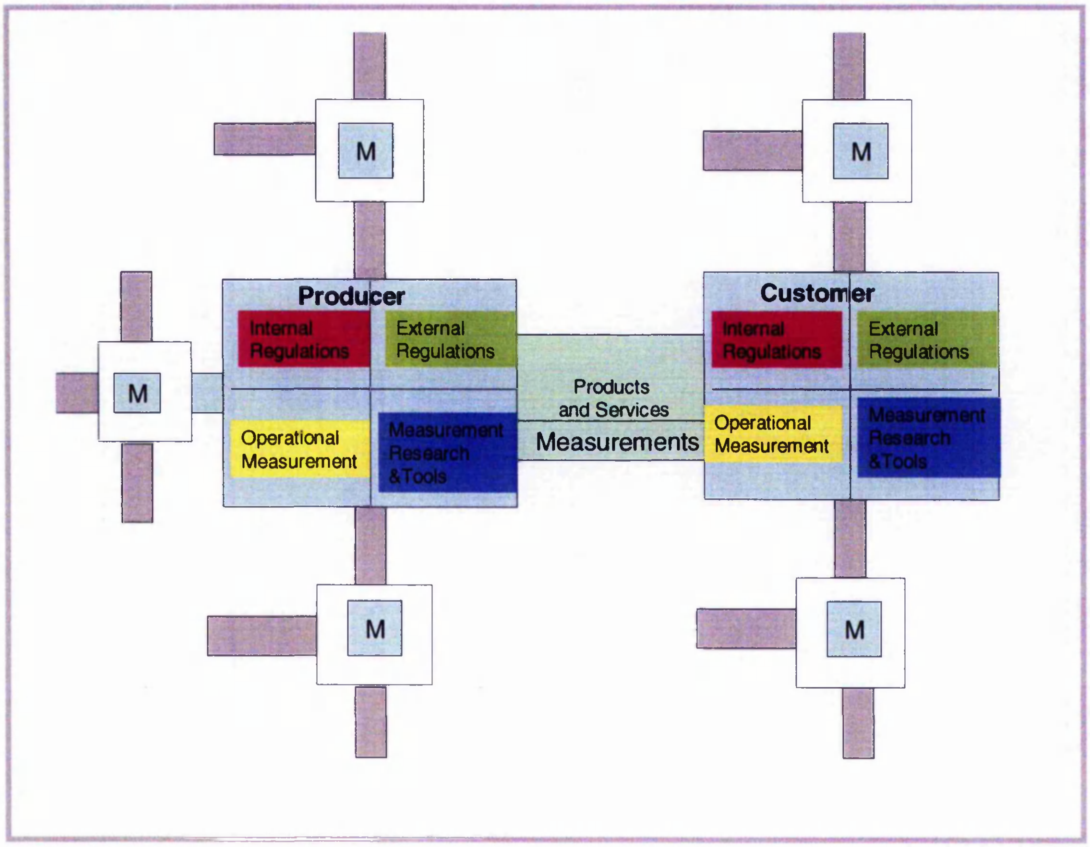

Figure 2.8 Simple Economic Map of Measurement Activity

(Source: Swann, 1999)

2.3.3 Measurement and Common Knowledge Pools

An interesting part of Swann's analysis is the link between measurement R&D, innovation and product differentiation. Swann (1999) argues that product innovation should not be seen simply as the improvement of particular product characteristics but, most importantly, also as the incorporation of new characteristics into products. This gives rise to a 'combinatorial character' to product innovation as new characteristics allow firms to form new combinations of new and existing characteristics. In this regard, measurement research may be thought of as creating a 'common pool' of measurable product characteristics.

The basic structure of Swann's model is as follows. The model is based on an economic technique called characteristics analysis (Abbott, 1955). This begins from an ordinary observation that products are differentiated by their features. Each of these features can be assumed as an axis in multidimensional space, so that the spectrum of competing products in a product space. Importantly, it can be shown that the behaviour of firms and customers in product spaces shows similarity to behaviour in geographical space. For example, innovative firms try to avoid highly congested product spaces unless they seek to cluster for agglomeration benefits.

The extent to which firms and customers can understand the space dimensions within which the products are located depends on measurement. Measurement, as the most important precondition allowing certain characteristics to be measured and evaluated by buyers, establishes the position of the product in characteristics space. An innovation based upon a new characteristic opens up the product space and will typically require new measurement methods as a prerequisite. In cases of vertical product differentiation[19], and where the demand for the superior characteristics is strong enough, producers will be able to charge a price premium. If consumer preferences are heterogeneous, then there will also be a demand for products which are horizontally differentiated, in which characteristics are present in different combinations, but there no general ranking in terms of quality.

In processes such as those above a combination of measurement and standardisation helps to create efficient markets (Swann 1999, 2000). The growth of new measurement activities adds value to both producers and customers by assisting in opening up product space. Moreover, such growth can be viewed as cumulative investment in measurement. As Swann (1999) asserts, the benefits from investment in measurement depend on the number of dimensions available. For simplicity, assume that the measurement investment programme is organised according to declining order of importance, that is, the most important activity is done first, followed by the less important one later. For single dimensional products, most of the benefits from the measurement programme occur at the start. However when there are complex new products with many characteristics, benefits accumulate nearer to the end of the measurement programme as there are more commercially significant characteristics to be measured.

[19] This refers to products belonging to the same industry but which differ in quality, such that consumers could agree on the order in which products should be ranked (Grimwade, 2001).

Common knowledge pools are therefore rather similar to the concept of an infra-technology. The important point is that the knowledge in the pool is somehow 'shared' between market participants. Standards represent codified evidence of such agreements. Costs of accessing the market are reduced because market participants can agree on the extent to which products embody specific characteristics.

Because they play such an important role in determining the effectiveness of metrology and measurement related research, it is worth considering the role of industrial standards in more detail.

2.3.4 The Economics of Standards

In a market economy, firms are usually assumed to maximise profits or shareholder value. Therefore, firms will invest in measurement, not only for operational measurement and improving measurement tools in order to gain and maintain a competitive edge and then extend the market share, but also to meet the internal and external regulatory standards in cost minimising ways. Where measurement is used to improve production processes, it should generally be possible to capture the benefits from improved quality control, achieving environmental standards in lowest cost ways, etc. Here standards may have an important informative role. Things are very different when it comes to product innovation however where (as we saw above) in the presence of information asymmetries, it is also necessary to convince consumers. In this aspect, perhaps it would be more precise to say that some parts of the economics of measurement have very similar features to the economics of standards (Swann, 2000).

Barber (1987) emphasises that industrial standards are the key factor that makes markets function effectively since their intended effect is to reduce both asymmetric information and transaction costs, i.e., the cost of accessing the market. Moreover, standards are also important for trade, productivity and innovation.

Standards are created through a variety of processes. In this regard, Clarke (2004) distinguishes between three types:

- *De facto*, or informal, standards which are produced by the unaided market;
- Institutional standards which are created as part of regulatory processes (technical regulations);
- *De jure,* or formal, standards that are created as part of a voluntary process of co-operation and consensus among interested parties. These are produced either by a formally established standards body or by a recognized professional body.

Standards can also be distinguished by their economic function; Swann (1999) studied the economic impacts of standards and concludes four broad types of effect that a standard can bring:

- to define interfaces and compatibility;
- to define minimum quality (e.g., safety standard);
- to achieve a reduction of variety; and
- to provide information and product description.

Table 2.4 gives practical examples of different types of standard and their associated functions. Much of the economic literature has concentrated upon the creation of compatibility and the consequent generation of so-called 'network externalities' but may also result in the development of undue and undesirable monopoly (e.g., David and Steinmuller, 1994). Measurement is however often a key element in ensuring compatibility between the products of different producers. Minimum quality or quality discrimination standards definitions can deter those producers with low quality and ensure a price premium for the high quality producers or sellers. Therefore, minimum quality standards have been regarded as an effective approach to overcome Gresham's Law, which is the phenomenon that 'bad drives out good'. As discussed by Swann (1999), suppose that buyers cannot distinguish high quality from low quality before purchase, and then it may be difficult for the high quality seller to sustain a price premium. Without such a premium, and if the high quality seller's costs exceed those of the low quality seller, then the former will lose their advantages in product quality and may eventually exit the market. Evidently, minimum quality standards help consumers to reduce transaction costs due to the largely removed risk and uncertainty of a product's characteristics. Variety reduction standards can foster economies of scale but on the other hand may have the disadvantage in the reduced choice for customers. Finally, standards of information and product description also help the reduction of transaction costs and facilitate trade.

	Function			
Type of standard	**Interoperability**	**Minimum Quality**	**Variety Reduction**	**Information**
Informal (de facto)	Microsoft Windows	Hotel star ratings	VHS video tape	Recycling data
Regulatory	Reporting procedures for company	Safety of toys	Petrol grades	International road signs
Formal (de jure)	The size of paper stationery (A4 etc)	Cycle lighting	Dry battery sizes	Signs designation public facilities

Table 2.4 Practical Examples of Different Types of Standard and Their Associated Functions

(Source: Temple P, and Williams G. - The benefits of standards. CEN 2002a)

A great many standards are of the formal (*de jure*) kind - a result of agreed work by the technical committees of national standardisation bodies (NSBs) such as the British Standards Institution (BSI)[20] and the German Deutsches Institüt füur Normung (DIN) and French Association Française de Normalisation (AFNOR) in Europe. By contrast, the US has no single standards body but a plurality which tends to reflect sectoral origins, such as American Society for Testing and Materials (ASTM).

During the last century, the standard organisations have been proliferating rapidly among European nations. Britain was and is still among the leaders of the standard organisations. Especially after World War II, many countries started to pay more attention to economic growth and boosting exports. The benefits of standards in maintaining service quality while allowing for service variety by introducing competitors had been well recognised. In the UK attention was directed to the marketability of products in the former countries of the Empire (History of British Standards, 2006). Meanwhile, the foundation of the International Organisation for Standardisation (ISO) arose from the requirement for internationally acceptable standards. On the other hand, the expansion of trade regionally since the World

[20] In this study we will focus on institutional standards.

War II has led to the development of regional standards bodies including the pan-European bodies such as the European Committee for Standardisation (CEN), the European Committee for Electrotechnical Standardisation (CENELEC), and The European Telecommunications Standards Institute (ETSI).

Today the heyday of national standards in Europe is largely past as the main work of the national standards bodies is geared towards the marketing of harmonized European standards often related to the development of EU Directives where standards play a key role in their application. The standards produced by and through CEN, CENELEC, ETSI and the NSBs take the form of documents, which in practice frequently relate to several of the underlying functions of standards. Most importantly they contain technical information which helps create the 'common pool' (Swann) and the 'infra-technology' of Tassey, closely related ideas. By hypothesis at this stage, the effective functioning of standards requires much measurement input. Like the patent counts which informed many studies into the role of technology, standards can also be counted and searched using modern digital technology to confirm this hypothesis. The final part of this chapter returns to this source of data on measurement. Before this is considered however, the literature review on the economics of measurement continues in the next section with a discussion of the few studies which have attempted to gather empirical information on the benefits of measurement activity.

2.4 Empirical Evidence Regarding the Economic Impact of Measurement

Somewhat ironically, the economic and social benefits (both direct and indirect) derived from measurement are difficult to pin down and measure. Most studies have adopted a case study methodology, but others have attempted to quantify the direct economic benefits of measurement with the aid of economic models, such as the Mapping Measurement Impact (MMI) model used in the UK (PA Consulting Report, 1999). This section will focus on attempts to evaluate the costs and benefits of measurement activities commissioned by the DTI (United Kingdom), EC (European Union) and US National Institute for Standards and Technology (NIST, United States), amongst others. These studies are based on the application of different economic approaches.

2.4.1 Studies Conducted by the Department Trade and Industry (DTI, UK)

Economic Model – the Mapping Measurement Impact (MMI) Model

The purpose of the Mapping Measurement Impact (MMI) model developed on behalf of the UK Government's Department of Trade and Industry (DTI) is to assist in evaluating and prioritising programmes which are publicly funded. The original structure of the MMI model is described in Klein *et al.* (1996). In early 1993, government expenditure funding of a number of measurement infrastructure projects in mass, length and flow at a cost of about £5 million per year was cancelled. In order to assess whether there was any injurious economic impact or whether the loss to the economy would be greater than the saving in expenditure, the MMI model was developed with the explicit aim of providing cost to benefit ratios of the publicly financed programmes of the NMS.

The design of the model was influenced by the opinions of actors situated in key positions within metrology related industries. Through a series of case studies, the views of a selection of these widely situated actors enabled the modellers to identify key linkages between work at the metrology laboratories and areas of industry that were considered to create value for the economy. These linkages were then characterised through five benefit mechanisms. The linkages derived from the various programme-related case studies are therefore an attempt to simplify the complexity through applying a common taxonomy of benefit mechanisms across the metrology programmes (Shearn, 2001). The five distinct value creation mechanisms that benefit by measurement for industries were established as being:

A. Providing traceability to internationally recognised primary standards.
B. Generating exploitable new measurement technologies.
C. Using leading edge metrology to support advanced products.
D. Providing an expert service, usually consultancy, to diagnose and solve measurement related problems in industry.
E. Providing leadership and dissemination in frontier technologies.

Figure 2.9 shows the structure of the model. Williams *et al.* (1999) noted the steps needed. Firstly, a survey of expert practitioner opinion is used to provide a score for the importance of each of these mechanisms for the programmes and project themes. A score metric from one to seven was used to indicate the significance of impact. The relation of the person scoring to the projects was captured through three self-assessment categories: expert, knowledgeable and aware (Shearn, 2001). Secondly, to investigate the impact assessment, the nature of the impact by each project in an NMS programme in each sector is classified as underpinning, direct or both. And finally economic benefit measure (EBM) was employed estimating for each project the net present value (NPV) of the extra benefit which it will deliver to UK industry. The NPV depends on data provided by secondary sources such as the national statistics office. Moreover, the EBM is divided by project costs to produce a single cost benefit ratio for each project (Williams *et al.*, 1999).

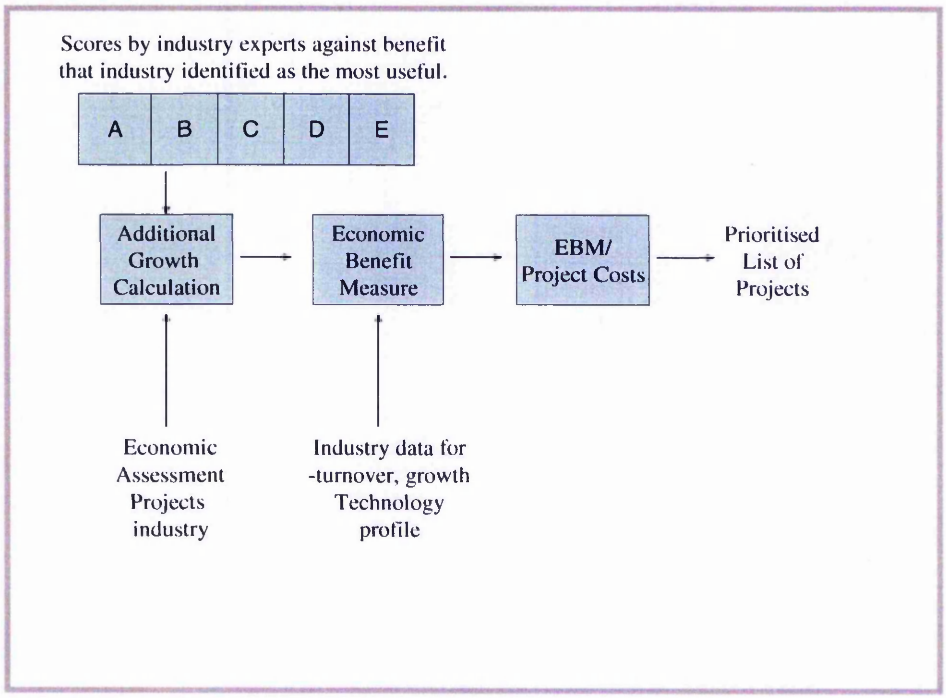

Figure 2.9 The Structure of the MMI Model

(Source: Williams *et al.*, 1999)

The final conclusion suggests that an annual output of £212 million and a trading profit of £46 million would be directly affected by the NMS cuts and would reduce growth in these sectors from 3.79% to 3.07% per annum[21]. In addition, given background understanding of

[21] Due to a variety of reasons, the results were only released at an aggregate level. Therefore it is not very clear what sectors were involved, or how large they were.

the UK metrology industry, weightings were derived from industrial surveys for each benefit mechanism (Shearn, 2001). The split of economic value between the mechanisms is shown below in Table 2.5.

Mechanism	Percentage of total economic value
Traceability	5%
Commercialisable Products	2%
Leading-edge calibrations	8%
Consultancy	54%
Leadership	30%

Table 2.5 Split of Economic Value Between the Mechanisms.

(Source: Klein, *et al.*, 1996)

One important development of the MMI model was the inclusion of a further two benefits mechanisms; F was addressed by Bowns *et al.* (2003) and G was developed by Williams *et al.* (1999). They were devised to capture other properties of the NMS, beyond innovation and traceability, which had been overlooked.

F. Representing UK interests on international bodies;
G. Facilitating compliance with existing regulation or legislation.

Bowns *et al.* (2003) estimated the publicly funded measurement R&D programmes by development of the MMI model. The model indicates that there were a number of selected projects with the benefit-to-cost ratios (BCR) varying from 5 to 111 with an average of 16 in 1999. Meanwhile, as reported by PA Consulting (1999), the analysis of the economic impact of eight case studies across very different measurement technologies shows both significant private benefits as well as externalities, providing strong evidence for the role of NMS in preventing market failure. The review by PA Consulting Group for DTI in 1999 – described in more detail below - provided a critical examination of economic and non-economic benefits for the NMS through three distinct approaches, namely direct measurement, case studies and measuring the economic impact:

- Direct Measurement: based on the pre-existing MMI economic model;
- Case Studies[22]: eight case studies which concentrate on how these different measurement technologies and deliver economic impact;
- Measuring the Economic impact: through the economic analysis, which includes econometric input/output analysis, trade flow and Total Factor productivity (TFP).

The results of the investigation recorded the NMS as delivering a surprising level of benefits. According to Williams (2002), based on the budget of £38 million in the year 1999, the NMS in the United Kingdom as a whole was estimated as having a significant impact on the economy of 0.8% of GDP, which equates to £5 billion per annum in terms of Total Factor Productivity. It is believed that this leverage of economic impact is exceptionally large. Generally, therefore, the investments in the national metrology infrastructure by the United Kingdom government have been considered by a number of studies as one of the best examples of government investments with a large return.

Evaluating the Impact of the National Measurement System: the 1999 Review

Swann's (1999) analysis highlighted the significance of market failures in the economics of measurement and hence the potential importance of economic policy and its attitude toward understanding the institutions comprising the National Measurement System.

In 1999, the UK government conducted a substantial review of the National Measurement System. This was conducted by PA Consulting (1999) with the objective of:

- Testing the rationale for and economic benefits of the NMS;
- To examine NMS programmes and possible future programmes to establish cost-benefit ratios for all major NMS activities;
- To assess the value of having centres of excellence.

[22] Example of case studies of the UK are grouped with the US later in this section.

The report summarized mechanisms where measurement where measurement has an impact. These are shown in Table 2.6.

a. Supporting innovation	Support for development of new products through generating new and better measurement techniques
	Enabling better understanding of phenomena
	Accelerating time to market by passing regulatory "hurdles" quickly.
b. Maintenance of the measurement infrastructure	Through providing traceability
	Supporting the calibration chain
	Maintenance of the knowledge pool and the dissemination of best practice
c. Enabling fair and safe competition	Providing confidence in health and safety
	Generating standards to meet new requirements
	Reducing information asymmetries between buyers and sellers and supporting legal metrology
d. Representing the UK	Protecting UK industry
	Building confidence in UK metrology
	And therefore UK products and standards and by working with other national measurement institutions

Table 2.6 The Economic Impact Mechanisms by the NMS

(Source: PA Consulting Report, 1999)

a. The Support of Innovation

The first impact mechanism is supporting innovation. Measurement technologies are closely linked with other forms of technology because they impose constraints on what can be measured and how measurement can be carried out. For example, in some industrial areas such as electronic materials, optics, ultra-high precision machining and ceramics, measurements of unprecedented accuracy are required and the absence of adequate measurement technologies can pose a significant barrier to innovation.

In addition, the PA Report declared that measurement techniques provide a potentially important element in determining the dynamic process of market selection. Often the process of competition leads to one product or service becoming dominant within the market and perhaps even setting the market standard. Under these circumstances the appropriate set of measures and measurement techniques will be provided by the specifications of the dominant product. Alternatively, after market selection of a dominant product or service, firms will be forced to compete on cost and quality grounds and will focus their attention on using new and more efficient measures and measurement techniques in an effort to gain competitive advantage by differentiating their product. Accepted and accurate techniques for measuring the product characteristics involved may be an important element in a process of product differentiation.

Innovation involves 'the successful exploitation of new ideas'. Measurement supports innovation at every step in the value chain from idea to finished product. In order to understand the role of measurement innovation the PA report utilised the so-called 'Stage-Gate Model' of the innovation process. This provides a simplified model of product development from concept development through to product launch. There are three main steps, namely creative concept, engineering design, and launch in the innovation process in which measurement plays a key role. Firstly, creative concept - when a new concept is born it needs to be tested quickly by measurement for feasibility. Secondly, engineering design - during scale-up to production accurate testing allows consistency to be checked and therefore the engineering process to be further refined. Finally, before launch the product must be tested to see whether it meets various regulations under industrial, national and international standards. In addition, it is worth highlighting here that as a product moves from being an innovation to growth and maturity and eventually decline, measurement continues to play an important role.

b. Maintenance of the Measurement Infrastructure

The second impact mechanism mentioned in the report is the maintenance of the measurement infrastructure in the United Kingdom. A fast, responsive measurement infrastructure improves firms' abilities to launch products in time and maximise profits from them, indicating the need for such a system to be national. In particular, in order to maintain the common knowledge pool for the knowledge and technology diffusion, the NMS, acting as the central arbiter of measurement infrastructure, carrying out a series of innovation programmes, providing traceability and supporting the calibration chain, effectively delivers high quality and highly relevant technical outputs to industry which positively impacts the UK economy.

c. The NMS and Competition

The third impact mechanism is competing fairly and safely. If we agree with that famous phrase 'Mathematics is the language of science' (Galileo, 1623), then possibly we won't disagree that 'metrology is the language of commerce' (Anon.). This perhaps can imply the essential impact of measurement technologies for the smooth conduct of transactions, not only from the consumer's point of view but also for those involved in manufacturing. Both sides must have confidence in the accuracy and reliability of the measurements upon which they depend. For the consumer, accurate and reliable measurements help to reduce the transaction costs due to the time and money saved on distinguishing the quality of the products. When products conform to an established standard, consumers can be assured that the products meet safety performance. For the manufacturer, within the production process, measurement ensures the accuracy of instruments used to monitor quality control.

d. Representation of the UK

The fourth impact mechanism concerns the representation of the UK in the international economy. The UK has a long and excellent history of measurement infrastructure development. The first Engineering Standards Committee was established in Britain in 1901 and now the British Standards Institution (BSI) is one of the most important standard institutions around the world. The higher measurement capability provides great benefits and confidence for the UK industry to compete in the EU and other markets. In addition, along with economic globalization, the agreement on measurement is essential for the conduct of international trade, since in the absence of agreement, trade is likely to be impeded. Within the EU the process of mutual recognition and harmonisation are key sources of demand for both measurement research and the development of industrial standards. The process of international standardisation is supported by measurement and is also extended by measurement research (DTI 1989). Therefore, it is generally recognised that the existence of a comprehensive measurement infrastructure is a precondition for the competitiveness of a modern industrialised economy.

Report Conclusions

The central conclusions of the report are as follows.

- There is a strong rationale for the NMS based on economic and non-economic benefits;
- The balance of investment of the NMS is sound as tested by assessment of the portfolio of programmes;
- A centre of excellence is valuable, but more competition and industrial partnerships would increase the delivered value;

- The NMS is well managed, but improvements to the delivery processes would further increase output;
- There is no clear strategy to show how the policy objectives will meet future industry and technical needs and to provide direction to the NMS.

(PA Consulting Report, 1999, p5-1)

The empirical basis for reaching these conclusions as well as other studies which evaluated aspects of measurement is considered in the next section.

2.4.2 Studies Conducted by the European Commission[23] (EC, EU)

Other empirical work within Europe includes important contributions by the European Measurement Project Team, whose studies include Temple and Williams (2002b), and Temple, Slembeck and Williams (2002). These studies provided a framework for considering the economic processes which determine the adoption and diffusion of measures and measurement techniques and the effects they have on economic activities at both the microeconomic and macroeconomic level (Spencer and Williams, 2002).

Temple and Williams (2002b) provided a comprehensive economics analysis that focuses on the investigation of the role of measurement activities in underpinning technological change and driving economic growth. More specially, based on endogenous growth theory, specific methods were employed to estimate the contribution of measurement to the UK's knowledge stock and also estimated the impact of R&D on productivity growth which established an estimate of the contribution of measurement to economic growth overall.

The methodology Temple and Williams used is based on the computation of an economy's knowledge stock. According to Bayoumi *et al.* (1999), knowledge stock comes from three main sources: domestic knowledge, foreign knowledge acquired by trade and foreign knowledge acquired by non-trade means such as FDI, joint research and EU funding (Temple and Williams, 2002b). Metrology as a whole will be part of the stock and measurement in

[23] European Commission, as the driving force and the executive body of the European Union, is a key stakeholder in the European Measurement System.

underpinning technologies that drive the growth of total factor productivity (TFP). TFP is the proportion of GDP growth that is not accounted for in changes in conventional inputs such as capital, labour and materials. While TFP growth has many sources, many studies have now began to ascertain the quantitative significance of R&D. Accordingly this study allocated:

- a proportion of GDP growth to TFP growth;
- a proportion of TFP growth to knowledge growth;
- a proportion of knowledge growth to metrology input.

The metrology component of the knowledge stock was estimated by means of a patent count. In other words, using the metrology related patents as a percentage of total patents to estimate the impact of metrology. The results were based upon the fact that an average of 11.2% of patents in the total UK patents were measurement related, and this proportion was applied to the aggregate knowledge stock. In this manner the study showed that – cumulated over time – measurement had contributed substantially to UK growth - around 2% of GDP. Moreover, estimates of the contribution of measurement to the overall R&D stock by sector shows that the electrical apparatus sector accounts for the highest number with 54.8%, the second sector is electricity gas and water with 39%, followed by non-electrical machinery and professional goods (instruments) - two sectors which are 28.2 % and 26.2% respectively.

Spencer and Williams (2002) provide another study that focused on a description of the scope and dimensions of measurement and testing activity in the EU as a whole. This study is divided into two main parts; the first part introduced the basic roles of measurement institutes such as national measurement institutes, accredited and non- accredited measurement organization, and also analyses the data for cost and benefits of measurement technologies across Europe. The second part carried out six case studies to investigate the economic role of measurement in the different sectors, i.e., automobile industry and pharmaceuticals sector.

In the first part, the calculation of the costs and benefits ratio, funding of NMI's turnover, certification costs and expenditure on measurement and instrumentation are tabulated for each EU country, and internal spending by industry on measurements based on discussions with industrial users is estimated at 1% of total industrial costs. Legal metrology and social spending is excluded. Total spending on measurement in EU is found to be 0.98% of GDP.

Total benefits comprise application benefits that are estimated based on econometric estimates of measurement contribution to aggregate final demand (GDP), and knowledge spillovers which are based on econometric estimates of measurement knowledge contribution to economic growth. Externalities and benefits to society are not estimated. Total benefits are found to be 2.67% of GDP for the EU as a whole giving a benefit to cost ratio (BCR) of 2.73 in the aggregate (Birch, 2003). These figures imply (even without taking into account the very large benefits to society in terms of health, safety and the environment) that for every Euro devoted to measurement activity nearly three Euros are generated, and if including the society impact, the benefits to cost ratio will be raised further. Moreover, the impact varies between different countries with Germany accounting for the highest impact in the EU group, where measurement produces significant economic returns equivalent to 4.7% of GDP with a value of benefit-to-cost ratio is 3.9. Italy, which had the lowest impact of the countries in this study, was 1% of GDP with a BCR of 1.46.

Apart from the calculation of the benefits and costs ratio, six case studies based on economic data and interviews with the industries concerned demonstrated that measurement plays an essential role in these sectors, for example, the automobile industry. The automobile industry is by any criterion one of the key industries in the economy of the industrialised world, creating a turnover of €321 billion and high value added amounting to €70 billion in 1997. Accurate, comparable and traceable measurements of almost all physical quantities and several chemical quantities (e.g., exhaust emissions) is required for constructing innovative, safe, energy-economic, low-cost maintenance and environmentally friendly cars, also leading to improved position of manufacturers in an extremely globalized and internationally competitive market (CIPM Report, 2003).

Employing a similar methodology to that of Temple and Williams (2002b), Temple, Slembeck and Williams (2002) presented another empirical economic assessment of the impact of measurement and testing infra-technology in Switzerland. The result shows that Switzerland is an important source of innovation in measurement, and the benefits of measurement activity in Switzerland is equivalent to around 3.27% of GDP.

2.4.3 Studies Conducted by the National Institute for Standards and Technology (NIST, USA)

The National Institute of Standards and Technology (NIST) - the national measurement institution of U.S. - was founded in 1901. The aims of the NIST is to promote U.S. innovation and industrial competitiveness by advancing measurement science, standards, and technology in ways that enhance economic security and improve quality of life (NIST, 2008). The NIST has carried out a number of case studies on the economic impact of its works in several specific areas such as chemicals, pharmaceuticals and so on. Most of the studies are based on the comparison of the costs of development of a certain measurement standard relating to certified reference materials and the estimated savings to a predefined group of users. There are two common methods to evaluate the economic impact, namely calculating a benefit-cost ratio (BCR) i.e., the ratio of the financial benefit to financial cost, and a rate of return to the nation, called social rate of return (SRR)(International Committee of Weights and Measures, CIPM Report, 2003).

As the name implies, the BCR is dependent on two elements, the calculation of costs and benefits. In general, the costs can be divided into direct costs and indirect costs. According to Link's (1996) suggestion, direct costs are those incurred by NIST and indirect costs are those incurred by industry to implement the research outputs. In other words, direct costs are public costs and indirect costs are private costs. For the identification of benefits, elements such as productivity, quality, time to market, market share and transaction costs were considered.

Link (1996) highlighted some examples of the technical output produced through NIST's research that create potential benefits by these elements, as seen in Table 2.7 below:

Economic Benefits	Example
Reducing transaction costs between companies and their customers through product acceptance test methods or practices	When studying the Computer Systems Laboratory's role in establishing conformance testing programs for the Structured Query Language(SQL) database language, SQL producers reported an average of 2.5 work-years per year reduction in effort to resolve procurement disputes with customers.
Increasing market share, especially in terms of the world market, as a result of increased productivity, increased quality, or reduced time-to-market	When studying the Manufacturing Engineering Laboratory's feasibility demonstrations of software error compensation techniques, coordinate measuring machine (CMM) manufacturers reported a reduced time to market of between two and five years for CMMs. This time-to-market savings translated into increased manufacturing productivity valued at approximately $79 million over the 1985-1995 periods.
Increasing industrial productivity as measured by an increase in production yield or by a decrease in research or production costs	When studying the Computer Engineering Laboratory's role in establishing Integrated Service Digital Network (ISDN) conformance testing methodologies and standards-based implementation agreements, it was learned that NIST activities allowed users of ISDN communication technology to realize a 20 percent annual increase in productivity through reduced communication costs.
Increasing the quality of industrial products through enhanced product performance and reliability, or reduced attribute variability.	When studying the Physics Laboratory's operation and maintenance of the Facility for Automated Spectral Calibration, also known as the FASCAL laboratory, qualitative information was collected from manufacturers of measurement equipment, lighting equipment, and photographic equipment documenting that, in the absence of NIST's spectral irradiance standards, equipment customers would be forced to accept greater uncertainty in products.
Reducing the time needed to get industrial products to market by shortening the R&D process	When studying the Electronics and Electrical Engineering Laboratory's research program in electro migration characterization, domestic producers of semiconductors reported time saved in R&D and improved R&D efficiency from implementing the results of NIST's electro migration research, and they valued these benefits to industry at (in 1991) about $4.1 million.

Table 2.7 Example of Economic Benefits, adapted from Link (1996)

In these studies the Social Rate of Return (SRR) is calculated over a period of time taking into account the investments made by the NIST and the benefits acquired by a selected number of enterprises benefiting from these NIST investments, and is expressed as the financial benefit as a percentage of the corresponding NIST financial investment. Appendix 2.3 provides a summary of recent economic impact studies of NIST laboratory research projects.

Apart from Appendix 2.3, there are still many other project studies carried out by NIST which employed these two common methods (BCR and SRR). Meanwhile, a study by Gallaher *et al.*

(2002) of transportation equipment industries, explores the effects of adopting the Standard for Exchange of Product model data (STEP), which is an international standard designed to address inter-operability problems encountered in the exchange of digital product information. Their study shows the benefit-to-cost ratio is 11.4 and the social rate of return is 36.1%, in addition, STEP has the potential saving of $928 million (2001) per year by reducing interoperability problems in the automotive, aerospace, and shipbuilding industries (Gallaher *et al.*, 2002). In addition, other case studies were based on surveys of the producers and users of high-tech products, for example, Leyden and Link (1992) find high multipliers to the infra-technology spend of the NIST which substantially obtain the benefits associated with its investments. For example, in the US optical fibre and electro migration characterization industries, according to survey, the SRR are 423% and 117% respectively. In a summary of 25 recent NIST studies, Leyden and Link (1992) show that the Benefit-Cost Ratio (BCR) ranges from 3 to 113 with an average of 29 and estimates of the social rate of return (SRR) varies from 33% to 1056% with an average of about 175%.

Semerjian and Watters (2000) provide a work which focuses on the impact of measurement and standards infrastructure on the national economy and international trade for the US. Two methodologies, i.e., case studies and calculations of BCR and SRR, have been employed to measure the results of NIST metrology R&D though an ongoing program of economic impact studies. The study shows that in some industrial areas such as radiopharmaceuticals and thermocouples, the total net benefits increase from a negative $0.21 million in 1990 to a positive $110.4 million in 2001 for radiopharmaceuticals. Over the same period, the net industry benefits for thermocouples rise from none to $2.79 million. The cost-benefit ratio is around 2.95. In addition to the analysis of the function of different measurement organizations, this study also showed that the measurements and standards infrastructure of a nation has become an increasingly critical tool for national trade and for removing technical barriers to global trade.

These studies not only investigated the benefits from industrial areas, but also those relating to society as a whole, in areas such as health care. For example, a survey by the National Academy of Sciences Institute of Medicine (1999) addressed the questions of how improved measurement accuracy could save lives, save a significant amount of time and money, and improve the quality of life. Moreover, in 2001 health care costs in the United States are estimated to have exceeded $1,300 billion per annum, which is about 14 % of the United

States' GDP. It is estimated that typically 10 % to 15 % of these costs are measurement related. The *Washington Post and Medical Laboratory Observer* has reported that 25 % to 30 % of health-related measurements are performed for non-diagnostic reasons (re-test, error prevention and detection). This means that potentially some $10 billion to $30 billion per annum could be saved (CIPM Report, 2003). Appendix 2.4 compares 5 case studies (3 from the US and 2 from the UK) related to measurement R&D in the US and UK. It can be seen all case studies generalise higher BCR values, which reflects the substantial benefits that measurement can bring. Appendix 2.5 summarized quantitative estimation results of these studies by different study groups, i.e., DTI, EC and NIST.

2.5 Quantifying Measurement for the Empirical Analysis of International Trade

The object of this thesis is to study the relationship between measurement and international trade. The present chapter has assessed and examined studies which assessed the institutional infrastructure supporting measurement in a modern economy, with special reference to the U.K. Theoretically, the important part played by measurement and the National Measurement System consists in the public good dimension of a large part of its output. At a very broad level, the NMS may be expected to have significant impacts on the cost of using the market (transaction costs) as well as the costs associated with innovation and product differentiation. By hypothesis, much of this public good effect takes place through the channel of standardisation, where databases exist which allow for this to be tested. The concluding part of this chapter now considers this and other empirical means of assessing the importance of measurement in modern economies and through which the impact of measurement on international trade can be assessed. The key ideas here are 'standards counts' and the use of instruments.

2.5.1 Standards Counts

Measures of Standards across Industries

The creation of industrial standards is one of the ways in which the NMS delivers benefits to industry and these can in principle be counted for the purpose of using these counts and considering their effects on trade flows. Arguably, sample counts can be used as a rough proxy for the benefit they create. However, for this purpose we need to be able to associate measures of trade flows (organised on a commodity basis according to the SITC with industry classifications (to obtain data on industrial characteristics) and match these with the standards data, both in total and by the extent to which they are 'measurement related,' i.e., relate to the measurement and testing of performance related characteristics. The methodology adopted here is to match each of the classifications to the International Standard Industrial Classification (ISIC). Thanks are due to Mr. Temple who provided the descriptors which allowed matching of the BSI's catalogue of standards to the ISIC and count them by searching the PERINORM© database[24].

Let us look at a simple example of one industry data collection for the year 2002 for which industrial characteristics data are available through the ONS input-output tables, and are available at approximately the 3-digit level. As an example, the 15.5 industrial subsection is described as 'Dairy products'. In the PERINORM programme, following Temple's categories, the search term is 'DAIRY* OR (ICE AND CREAM)'. To count the total standard stock, types in the main descriptor of the industry, then enters a particular year. In this case the total standard stock in year 2002 for the 15.5 industry is 176. To count the measurement related standards, the search term is narrowed to include (measur* or determin*) and (test* or analys* or method*). A broader count of measurement related standards was obtained by the term (measur* or determin* or, test* or analys or method*) where * is the wildcard operator[25]. Hence, the number of narrow and broad measurement standards of industry 15.5 is 122 and 167 in 2002 respectively. Following this method, the data of other industries for 2002 can be obtained (by counting only those standards available in 2002). Figure 2.10 below illustrates the data of narrow and broad measurement standards in 2002 drawn to a natural log scale. The lnarrow is the log of the number of standards by the narrow definition, and the lbroad is the natural log of the number by the broad definition. Clearly, they are positively correlated.

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[24] A database of standards produced by a consortium of DIN, BSI and AFNOR.

[25] The principle of narrow search term is based on the intersection of measurement and reference to a test procedure, while a broad search term allowed for a reference to either measurement or a test procedure (Choudhary *et al.*, 2006).

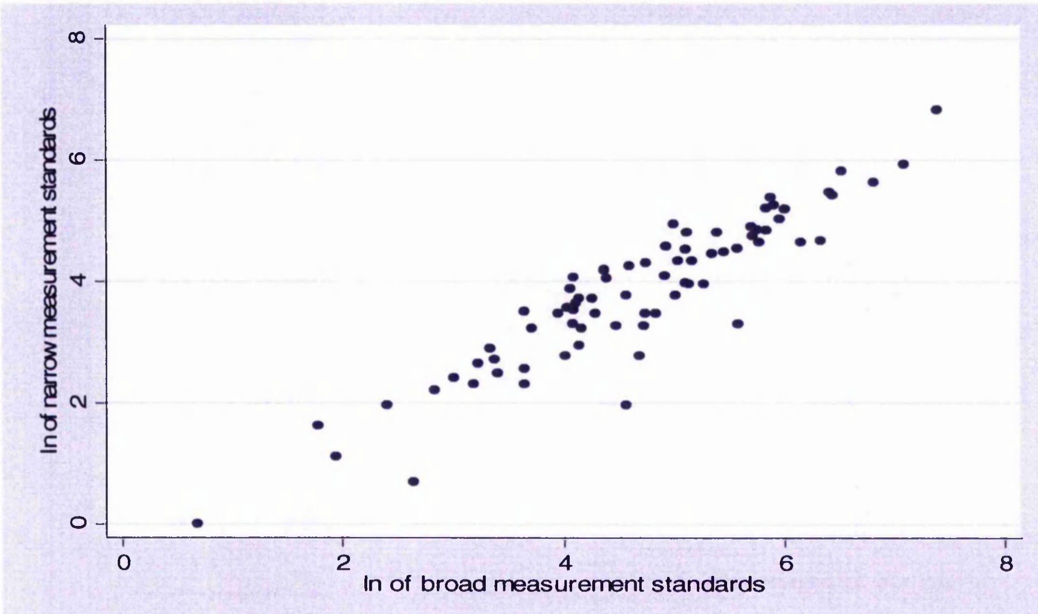

Figure 2.10 Count of Measurement Related Standards by SIC

With the UK's international trade flow data available from 1992 to 2002, matching narrow and broad measurement related standards as well as the total stock for the same period was collected for a total of 75 industries. Data for total, narrow and broad measurement standards in the year illustrated (2002) were sorted according to descending narrow measurement standards in order to analyse the characteristics of data as seen in Table 2.8.

		As at 31/12/2002	As at 31/12/2002	As at 31/12/2002	Year 2002
SIC(92)	Industry	Stock of Narrow Measurement Standards (Number)	Stock of Broad Measurement Standards (Number)	Stock of Standards (Number)	Purchase of Instruments (£ million)
33	Medical, precision and optical instruments	918	1614	1903	891.97
29.1	Machinery for the production	374	1201	2118	27.20
31.4to31.6	Electrical equipment	334	679	843	39.25
31.1+31.2	Electric motors	275	910	1215	52.60
31.3	Insulated wire and cable	234	605	754	3.87
28.4+28.5	Forging, pressing, stamping	224	628	1200	31.88
23	Coke, refined petroleum products	217	357	418	1.47
32.3	Television and radio receivers	191	370	500	62.50
24.3	Paints, varnishes coatings,	182	344	428	7.63
29.2	Other general purpose machinery	178	408	564	13.08
29.7	Domestic appliances	151	387	485	29.36
24.13	Other inorganic basic chemicals	140	148	158	16.17
26.1	Glass and glass products	133	303	378	3.77
25.2	Plastic products	127	318	382	31.50
26.4to26.8	Bricks, tiles	125	345	519	14.85
15.5	Dairy products	122	167	176	3.91
27.4	Basic precious	122	221	328	21.15
34	Motor vehicles, trailers	114	305	550	650.62
35.3	Aircraft and spacecraft	106	561	1385	90.94
32.1	Electronic valves and tubes	104	467	546	30.00
32.2	Television and radio transmitters	104	323	450	80.37
15.4	Animal oils and fats	97	138	144	0.46
18	Wearing apparel	94	265	321	2.38
27.1to27.3	Basic iron and steel	92	166	233	93.76
25.1	Rubber products	88	236	255	5.34
29.4	Machine tools	86	211	422	1.18
21.2	Articles of paper	76	176	217	2.61
36.4+36.5	Sports goods, games and toys	76	155	174	0.69
24.5	Soap and detergents	74	116	128	24.65
22	Printing of recorded media	70	99	143	4.45
15.6	Starch products	66	79	84	3.65
24.14	Other organic basic chemicals	65	79	89	99.69
21.1	Pulp, paper and paperboard	60	137	166	1.62
24.6	Other chemical products	58	60	61	23.01
24.16+24.17	Plastics and synthetic rubber	57	81	92	47.60
35.2+35.4+35.5	Other transport equipment	53	166	251	4.13
20	Wood and wood products	52	171	241	14.79
28.7	Other fabricated metal products	52	196	393	24.49
15.2+15.3	Fish, fruit and vegetables	48	58	63	3.77
17.2	Textile weaving	43	97	139	1.11
36.1	Furniture	43	151	194	12.12
15.7	Prepared animal feeds	41	71	77	6.81
24.11+24.12	Industrial gases	41	63	69	21.66
24.15	Fertilizers and nitrogen compounds	38	61	68	8.88
15.1	Production meat products	35	56	60	15.36
17.1	Spinning of textile fibres	34	60	75	0.26
15.98	Production of mineral waters	33	38	41	4.03

		As at 31/12/2002	As at 31/12/2002	As at 31/12/2002	Year 2002
SIC(92)	**Industry**	**Stock of Narrow Measurement Standards (Number)**	**Stock of Broad Measurement Standards (Number)**	**Stock of Standards (Number)**	**Purchase of Instruments (£ million)**
17.1	Spinning of textile fibres	34	60	75	0.26
15.98	Production of mineral waters	33	38	41	4.03
15.85to15.89	Other food products	32	52	65	4.39
26.2+26.3	Ceramic goods	32	127	148	3.41
29.3	Agricultural and forestry machinery	32	73	126	0.34
29.5	Other special purpose machinery	32	114	174	3.58
30	Office machinery and computers	27	268	565	300.46
35.1	Building ships and boats	27	59	116	90.26
28.1	Structural metal products	26	113	192	36.21
28.6	Cutlery, tools	26	88	212	7.13
17.51	Carpets and rugs	25	64	71	0.87
24.7	Man-made fibres	25	41	58	9.95
28.2+28.3	Tanks, reservoirs	19	63	90	32.20
16	Tobacco products	18	28	29	0.83
19.3	Footwear	16	109	119	0.19
36.6+37	Miscellaneous manufacturing	16	55	109	4.00
24.4	Pharmaceuticals, medicinal chemicals	15	29	39	53.72
17.6+17.7	Knitted and crocheted fabrics	14	25	37	0.93
24.2	Pesticides	13	38	39	10.72
17.52to17.54	Other textiles	12	30	46	1.14
19.1+19.2	Tanning and dressing of leather	11	20	30	0.23
17.4	Made-up textile articles	10	24	28	1.18
27.5	Casting of metals	10	38	85	21.72
36.2+36.3	Jewellery, musical instruments	9	17	21	0.78
15.91to15.97	Alcoholic beverages	7	11	16	8.06
17.3	Finishing of textiles	7	97	108	0.27
15.83	Sugar	5	6	7	1.57
15.81+15.82	Pastry goods and cakes	3	7	9	8.21
29.6	Weapons and ammunition	2	14	19	5.16
15.84	Cocoa; chocolate	1	2	3	3.71

Table 2.8 Number of Narrow, Board and Total Standards Stock and Instrumentation in Year 2002 (ranked in order of narrow measurement standards)

(Source: PERINORM Database and ONS, UK)

It is clear from Table 2.8.that the highest number of standards stock in year 2002 is SIC 29.1 industry (Machinery for the production and use of mechanical power) followed by industry SIC 33 (Medical, precision and optical instruments) and SIC 35.3 industry (Aircraft and spacecraft). The highest number of narrow measurement standards is found in industry SIC 33 (Medical, precision and optical instruments, watches and clocks) i.e., by the industry actually producing the means of measurement – instruments. This is followed by SIC 29.1

(Machinery for the production and use of mechanical power) with the third industry SIC 31.4 to 31.6 (Electrical equipment). For broad measurement standards, the pattern is similar – the highest number is again industry SIC 33 and the second is SIC 29.1. For the total standard stock, SIC 29.1 industry accounts ranks first and SIC 33 is second, with aircraft and spacecraft industry at third position. In addition, compared with narrow measurement standards, the number of broad measurement standards accounts for a big component of total standards stock in each industry; roughly there are 71 industries occupying over half of total standards stock. Around 50 industries show narrow measurement standards constituting more than one third of total standards stock.

However, there may be interesting phenomena between these three variables. Some industries have a relative higher number of standards stock but a relatively lower number of narrow measurement standards, such as industry SIC 35.3 (Aircraft and spacecraft). This may be due to de facto standards issues. Some industries with monopoly power may set their own market standards. Therefore the narrow measurement standards published by BSI may be relatively lower than others.

The instrument sector plays a key role in the analysis in this thesis. Some medical, precision and optical instruments companies have entered the 100 top sale companies in Europe according to their highest annual sales. Of course, SIC 33 (broadly defined as the manufacture of instruments) is, as the PA Consulting report (1999) suggests, supported by the NMS and turnover in 1999 was around £6.3bn with trade surplus around £1.2bn per annum.

2.5.2 Use of Instruments

As the previous section suggests, a different idea of the importance of measurement across industries can be obtained by considering the use of the means of obtaining measurements, i.e., via the use of instruments.

Use of Instruments across Industries

The data on the use of instruments in the UK can be derived from the ONS Supply-Use tables. In the Use table, each column shows the industry needs of the particular products; each row shows the product used by different industries. Thus the instrument products show different demand by each industry. The value of purchase of instruments by each industry in 2002 is shown in column 4 of Table 2.8. Some industries such as SIC 34 (Motor vehicles, trailers) show relatively higher instruments used but with relatively lower narrow measurement standards; this possibly due to the fact that vertical integration characteristic of the motor vehicles industry thus most parts are produced by different factories before final assembly. Appendix 2.6 shows the instruments used by different industries in an example year 2002.

From Appendix 2.6, it can be seen that industry SIC 33 (Medical, precision and optical instruments, watches and clocks) is the highest sector in its use of instruments. This is followed by SIC 34 (Motor vehicles, trailers and semi-trailers) and SIC 30 (Office machinery and computers) that account for second and third respectively. Others such as SIC 24.14 (Organic Chemicals), SIC 27.1 to 27.3 (Manufacture of basic metals such as Iron and steel) and SIC 35.3 (Aircraft and spacecraft) are also present in the higher ranges. Obviously, these top six industries make great use of measurement techniques. In addition, SIC 33 is the instrument manufacture industry that directly obtains much of the benefit from NMS. Figure 2.11 shows the trend of these six top industries from the years 1992 to 2002. Obviously, Medical, precision and optical instruments industry is the highest value in this group and its use of instruments has been increasing over time. In 1992 the value of instrument use was £484 million increasing significantly to £892 million in 2002. The industries of motor vehicles, trailers and semi-trailers and office machinery and computers also show this increasing trend during the same period, especially industries of motor vehicles which increase sharply from 1999 to 2002. Aircraft and spacecraft industry peaked at £243 million in 1996 and then dropped at the lowest point to around £90 million in 2002. The other two industries, manufacture of basic metals such as iron and steel industry and organic chemicals illustrate a roughly stable trend.

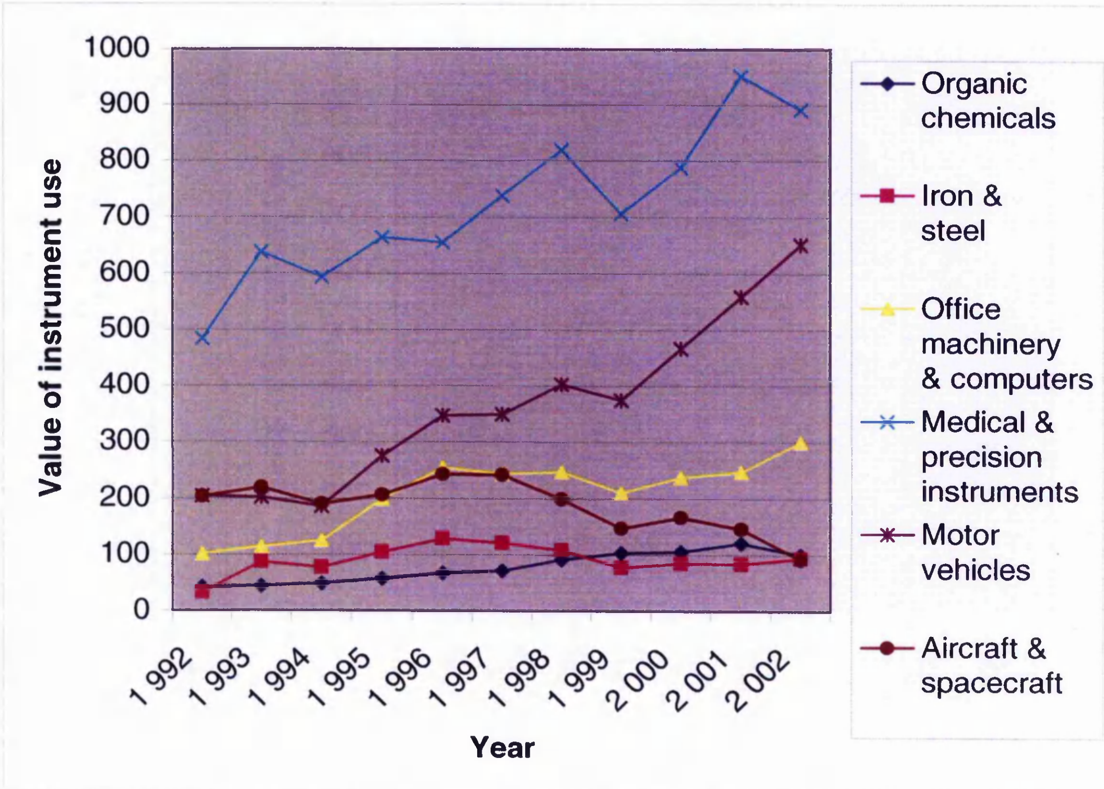

Figure 2.11 The Trend of Top Six Industries for Years 1992 to 2002

Apart from analysis of instrument use by different industry sectors, there may be another characteristic of instrumentation across countries that forms part of the measurement infrastructure and can be viewed as an important indicator in evaluating the different measurement capability of nations. In addition, Appendix 2.7 lists the comparison of scatter chart between the standards measure and the use of instruments. Clearly, for standards stock, narrow measurement and broad measurement with instrumentation are positively correlated, especially for the case of narrow measurement with instrumentation.

Use of Instruments across Countries

While in theory different countries in the EU should have access to the same measurement infrastructure, the fact is that the EU consists – even prior to the recent enlargement - of a large variety of nations both competing and cooperating - a characteristic of Europe over many centuries. Different nations with different languages and cultures are likely to create different measuring units and measurement standards over a long period of time. Therefore, the current measurement infrastructure across individual EU countries still takes quite different forms and may imply different measurement capabilities. Post-1992, it is no longer possible to consider using a standards count across countries to compare these capabilities (since as we have seen most standards today emerge from the European standards bodies and are then marketed through the national bodies). An alternative is simply to consider the use of instruments (i.e., consumption by country). With the data[26] from Spencer and Williams' report (2002) in terms of production, sales and trade in the EU measurement and testing industry has been used to calculate the total measurement instrument consumption for each EU country. The study then assumes that the data can be served as a proxy to represent a country's competitive advantage arising from measurement against its partner countries.

To summarise, both standards and the instrument sector are closely related to the national measurement system. Therefore, they provide two plausible indicators of variations in the importance of measurement and measurement capability both between industries and between countries.

2.6 Conclusions

This chapter has investigated the economic role of measurement from four main perspectives. First it introduced the concept, structure and function of measurement infrastructures, and its role in supporting the economy. Second, it discussed a number of important theoretical rationales of the economics of measurement, investigated by Tassey in the U.S., Swann in the UK and others. Third, it provided a literature review of empirical studies to examine the economic impact of measurement. And finally, it suggested different ways of indicating the importance of measurement both across industries and between countries.

In Section 2, the key finding was the significance of the NMS for the knowledge processes supporting technological change. This support consists of various elements including state of the art research programmes, accurate measurement calibration services, and standards which were identified as an important channel through which the benefits of the NMS were taken up by industry.

[26] The data from the report is collected in 1999/2000.

Section 3 considered several important theoretical rationales for looking at measurement as a vehicle linking science to the market. Pioneering work by Tassey (1992), Leyden and Link (1992) identified measurement as a form of 'underpinning' technology or infra-technology that supports other activities such as production, innovation and marketing. This included the codified information, emerging from metrology on the basic science, the support of the development of generic technology, through providing highly precise measurement and evaluated scientific and engineering data, as well as providing the technical basis for standards to assure product quality and reduce transaction costs in using the market. In these ways measurement plays an important role in supporting market activities. Perhaps the most important economic characteristic of measurement is its public good aspect, which may reduce the cost of product differentiation and associated market risks. Measurement is therefore linked to increasing variety - a hypotheses that will be developed in chapter 4. This idea was expressed in the common knowledge pool model developed by Swann (1999), which related measurement to R&D, innovation and product differentiation, and in which measurement research could be viewed as creating a 'common pool' of product characteristics. Finally, the economics of standards were briefly reviewed and the input from measurement assessed.

Section 4 presented a literature review of a number of empirical studies regarding the economic impact of measurement. Most studies adopted a case study methodology and found measurement contributed substantial benefits to the economy and society as a whole, with only a limited number attempting a modelling approach.

Section 5 - with a view to the empirical tasks ahead in this thesis - considered indicators of the importance of measurement both across industries and countries. Both 'standards counts' and 'the use of instruments' can be viewed as possible indicators. Focusing in the one industry dimension, a reasonable correlation was established between an industry's use of instruments – as obtained from the UK Supply-Use tables, and an industry's use of measurement related standards.

There are clear implications from the analysis in this chapter for the empirical analysis of international trade, both through the potential impact of measurement in innovation, and through reduction in transaction costs. Accordingly, the next two chapters will consider first the role of technology in generating patterns of trade and (in chapter 4) the specific impact of measurement in generating product variety, and intra-industry trade.

APPENDIX

Appendix 2.1

Funding of National Measurement Institutes (NMIs) in Europe (Percentage distribution by source).

	Total Income € m	Core Government Funding	European Union	Commercial Activity	Industrial Partnerships	Other	TOTAL (%)
Austria	**5.8**	86.0	0.0	14.0	0.0	0.0	**100**
Belgium	**3.2**	100.0	0.0	0.0	0.0	0.0	**100**
Denmark	**5.4**	24.3	3.1	56.8	2.2	13.7	**100**
Finland	**7.8**	78.0	0.6	14.6	1.5	5.4	**100**
France	**24.0**	86.3	4.8	8.4	0.2	0.2	**100**
Germany	**235.0**	90.8	1.4	3.9	3.8	0.0	**100**
Greece	**1.0**	73.8	0.0	26.2	0.0	0.0	**100**
Ireland	**4.0**	71.1	1.3	27.6	0.0	0.0	**100**
Italy	**21.5**	71.8	2.6	19.7	3.3	2.6	**100**
Netherlands	**15.8**	56.0	3.0	41.0	0.0	0.0	**100**
Portugal	**8.0**	9.8	0.1	90.1	0.1	0.0	**100**
Spain	**6.2**	58.8	11.8	14.7	2.0	12.7	**100**
Sweden	**45.8**	10.0	2.0	82.0	6.0	0.0	**100**
United Kingdom	**139.0**	47.9	2.4	47.5	2.2	0.0	**100**
European Union	**30.0**	0.0	90.0	10.0	0.0	0.0	**100**
Totals	**552.0**	**63.9**	**6.8**	**25.9**	**2.9**	**0.5**	**100**

Data source: Spencer and Williams, 2002.

Data for Luxemburg is not available.

Appendix 2.2

Example of the Flow Programme

Flow measurement is vital to many industrial sectors, such as water supply, oil extraction, gas distribution and much of the process and pharmaceutical industry depend on flow meters for quality control and custody transfer. Generally, accurate measurement is a prerequisite for monitoring and controlling all industrial processes. On the other hand, wrong or inaccurate measurements can lead to wrong decisions that can have serious consequences, costing money and even lives. In particular for the flow measurement, "A 1% error in flow measurement is equivalent to approximately £200 million per year of UK oil production." (Flow Programme NEL, 2005).

Like other programmes, the latest Flow Programme covers a 3-year period from October 2005 to September 2008. The objectives are four-fold:

- To provide and develop the UK's national infrastructure for flow measurement;
- To carry out generic research into industrial flow measurement problems;
- To provide traceability to UK primary standards of the individual components of flow rate (volume, mass and time) and of all ancillary measurements (density, temperature, pressure etc); and
- to ensure international compatibility and credibility of the UK Standard by inter-comparison with other National Standards worldwide.

Moreover, the Flow Programme contains totally 23 projects such as national gas flow measurement standards, national oil flow measurement standards and so on, however, these projects can group into 6 key themes as follows:

- Linking the macro scale to micro and nano- technology[27];
- Technology innovation;

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[27] Nanotechnology is defined as a technology in which 'dimensions and tolerances in the range 100nm (0.1 microns) to 0.1nm play a critical role (Franks, 2007).

- Meeting Emerging requirements;
- Supporting environmental & regulatory compliance measurement techniques;
- Underpinning Metrology; and
- Knowledge transfer, management and formulation.

The first 4 themes are research projects, which address the main requirements identified in the formulation process. Themes 5 and 6 provide the supporting infrastructure for these projects. Figure A 2.1 shows the key market sectors where the research project portfolio is expected to have major economic impact within the next 3-10 years. These sectors make a huge contribution to the UK economy. Figure A 2.1 highlights where individual projects will have a direct impact on individual sectors. It can be seen that two key projects, project 2.1 - 'underpinning flow measurement in challenging fluids' which is under the second theme of Technology Innovation, and project 3.1 - 'measurement requirements for liquefied natural gas, liquefied petroleum gas, compressed natural gas and hydrogen' which under the third theme of Meeting emerging requirements, impact on a number of a different industrial sectors, such as chemical industry, oil and gas production, energy production, food and drink sector for project 2.1, and chemical industry, energy production, gas transport and distribution and automotive and so on for project 3.1. To summarise, the flow research projects provide sophisticated knowledge, innovative solutions and novel flow measurement techniques, which underpin virtually all of the key processes within industrial sectors. Innovation to increase accuracy and efficiency in these areas of science is therefore having a significant impact on the UK economy.

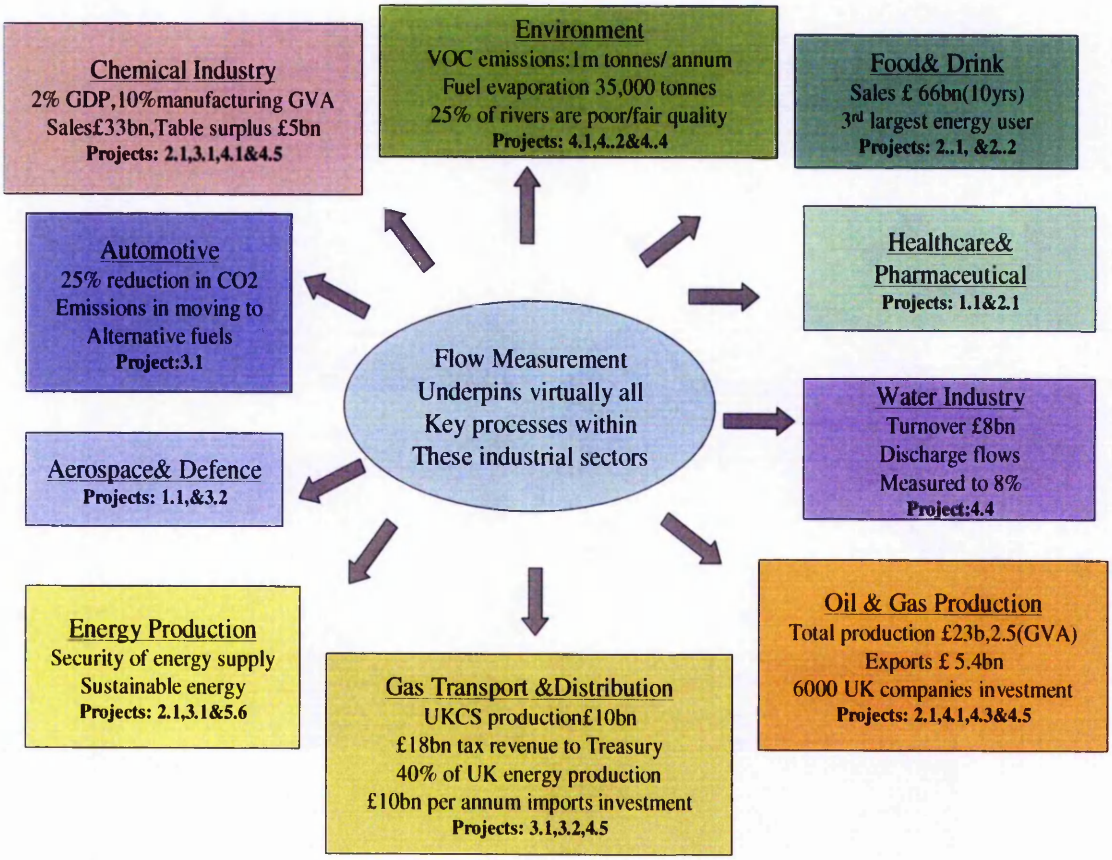


Figure A 2.1 Impacts on UK Economy and Industry

(Source: Flow Programme, 2005-2008)

Appendix 2.3

Summary of Recent Economic Impact Studies of NIST Measurement and Standards Laboratory Projects

Industry: Project	Output	Outcomes	SRR	BCR
Photonics: optical instruments	Test method (calibration)	Increase productivity, Lower transaction costs	145%	13:1
Automation: machine tool software error compensation	Quality control algorithm	increase R&D efficiency, Increase productivity,	99%	118:1
Materials: thermocouples	Reference data (calibration)	Lower transaction costs, Increase product quality	32%	3:1
Pharmaceuticals: Radiopharmaceuticals	Reference materials	Increase product quality	138%	97:1
Chemicals: Alternative refrigerants	Reference data	Increase R&D efficiency, Increase productivity,	433%	4:1
Materials: phase equilibrium for advantaged ceramics	Reference data	Increase R&D efficiency, Increase productivity,	33%	10:1

SRR = social rate of return;
BCR = benefit-cost ratio

Source: Tassey, 1999.

Appendix 2.4

Comparisons of Measurement Case Studies in the UK and US[28]

	Case Study	Description	Outcomes	Measures
US	Energy (EEEL/1995)	Test methods in electric meter calibration	Lower transaction costs	SRR: 117% BCR: 12
	Automation (MEL/1996)	Quality control algorithm, machine tool software error compensation	Increase R&D efficiency Increase productivity	SRR: 99% BCR: 85
	Manufacturing (MEL/2002)	Standards development (STEP), conformance test methods/services	Increase quality and assimilation of standards Accelerate standards development	SRR: 32% BCR: 8 NPV: $180M
UK	Warm Petrol	Review the traditional method of measuring petrol by a mass basis; reduce alleged losses experienced by retails due to contraction of petrol after delivery	Reduce transaction costs both for retailers and consumers Economic impact in helping safe and fair competition	Saving retailers a cost of £150 million for compliance with legislation Total of £930 million benefit attributable to the impact of legislation A potential BCR 14.4
	Vauxhall on-line measurement system	Introduction of on-line measurement system	Supporting innovation Support industry infrastructure Cost saving to the producer	Private benefits£1.87 million of the five-year life in terms of labour saving, reduction of re-work and warranty claims A potential BCR 17

Note:

SRR : social rate of return
BCR : benefit-cost ratio
NPV : net present value

[28] The case studies in the US can be found at NIST's website at: www.nist.gove/director/planning /studies.htm; The case studies in the UK are taken from PA Consulting Report, 1999.

Appendix 2.5

Summarise of Quantitative Estimation Results of Studies by Different Studies Groups, i.e. DTI, EC and NIST.

UK	
Topic	Measuring the Economic Benefits from R&D: results from the mass, length and flow programs of the UK national measurement system
Author	Klein, *et al.*
Year	1996
Methodology	MMI model
Results	An annual output of £212 million and a trading profit of £46 million would be directly affected by the NMS cuts. Moreover, it would be to reduce growth in these sectors from 3.79% to 3.07% per annum
Topic	Measuring the Economic Benefits from R&D: Improvements in the MMI Model of the United Kingdom National Measurement System
Author	Brown *et al.*
Year	2003
Methodology	MMI model
Results	A number of selected projects with the benefit-to-cost ratios (BCR) varying from 5 to 111 with an average of 16 in year 1999.
Topic	Department of Trade and Industry National Measurement System Policy Unit, Review of the Rationale for Economic Benefit of the UK National Measurement System
Author	PA Consulting Group
Year	1999
Methodology	MMI model, Case studies and economic analysis (econometric input/output analysis, trade flow and Total Factor productivity).
Results	The measurement in the United Kingdom as a whole delivers a significant impact on the economy of 0.8% of GDP, which equates to £5bn per annum in terms of TFP.

Appendix 2.5 – cont.

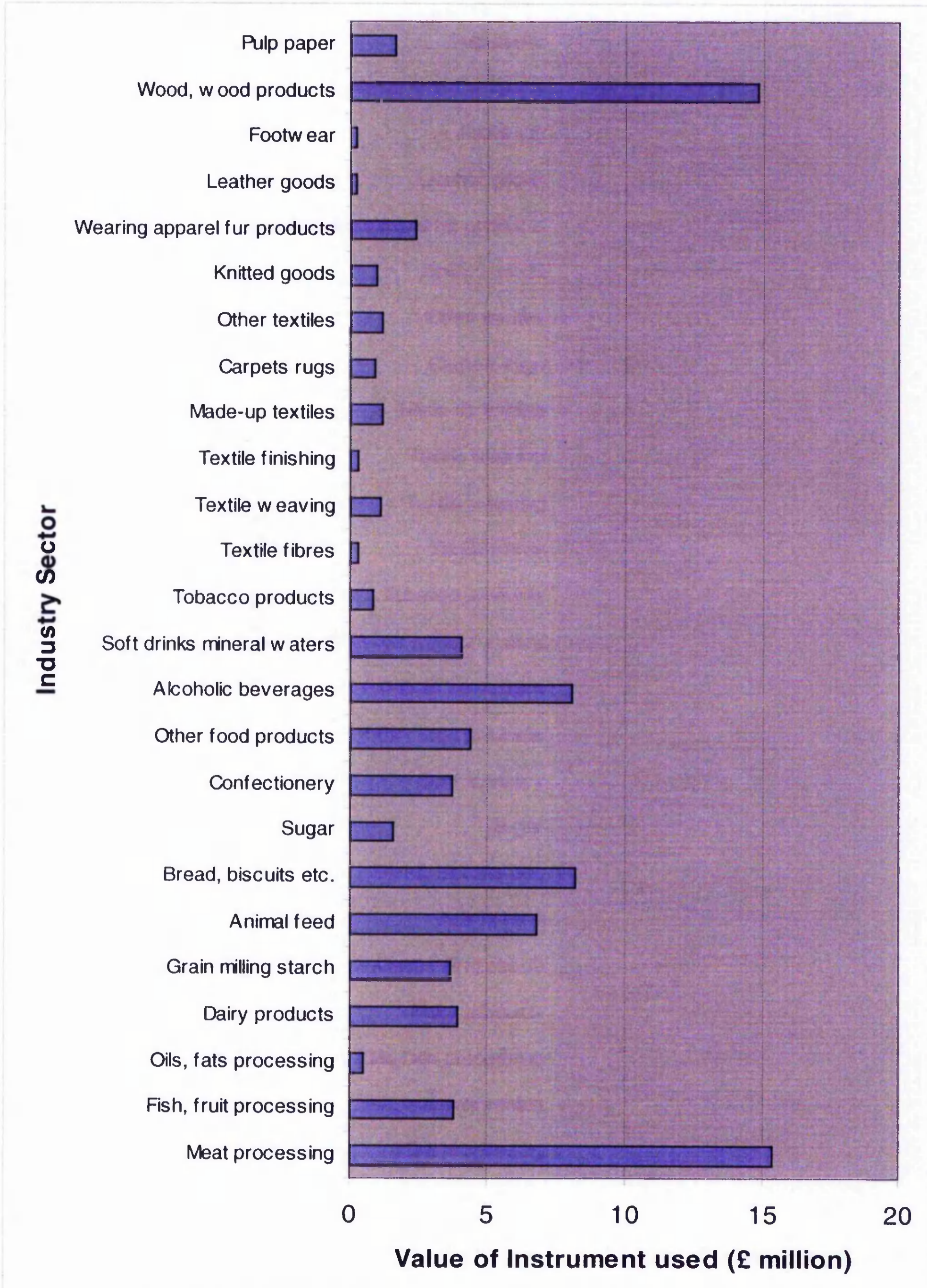
EU	
Topic	Infra-Technologies and Economic Performance: Evidence from the United Kingdom Measurement Infrastructure
Author	Temple and Williams
Year	2002
Methodology	Econometric input/output analysis, trade flow and Total Factor productivity
Results	An average estimate of 11.2% of measurement related patents in the total of all UK patents in particular years. In addition, measurement R&D has a significant impact, equivalent to around 2% of GDP.
Topic	The Scope and Dimensions of Measurement Activity in Europe
Author	Spencer and Williams
Year	1999
Methodology	MMI model, Case studies and economic analysis (econometric input/output analysis, trade flow and Total Factor productivity).
Results	Total benefits are found to be 2.67% of GDP for the EU as a whole giving a benefit to cost ratio (BCR) of 2.73 in the aggregate.
Topic	An Economic Assessment of the Impact of Measurement and Testing Infra-technology in Switzerland
Author	Temple, P., T. Slembeck and G. Williams
Year	2002
Methodology	Economic analysis (econometric input/output analysis, trade flow and Total Factor productivity).
Results	The benefits of measurement activity in Switzerland equivalent to around 3.27% of GDP.

Appendix 2.5 – cont.

NIST	
Topic	Number of case studies conducted by NIST, such as Leyden and Link (1992) and Gallaher *et al.*, (2002)
Author	
Year	
Methodology	Case studies, BCR, SRR and so on
Results	Recent 25 case studies from NIST show that the Benefit-Cost Ratio (BCR) ranges from 3 to 113 with an average of 29 and estimates of social rate of return (SRR) varies from 33% to 1056% with an average of about 175%.
Topic	Impact of measurement and standards infrastructure on the national economy and international trade
Author	Semerjian and Watters
Year	1999
Methodology	Case studies, BCR and SRR
Results	The total net benefits increase from -$210,000 in 1990 to $110,441 in 2001 for radiopharmaceuticals. During the same period, the net industry benefits rise from none to $2,791,800 for thermocouples and its cost-benefit ratio is around 2.95.

Appendix 2.6

The Instruments Are Used by Industry Sectors in Year 2002



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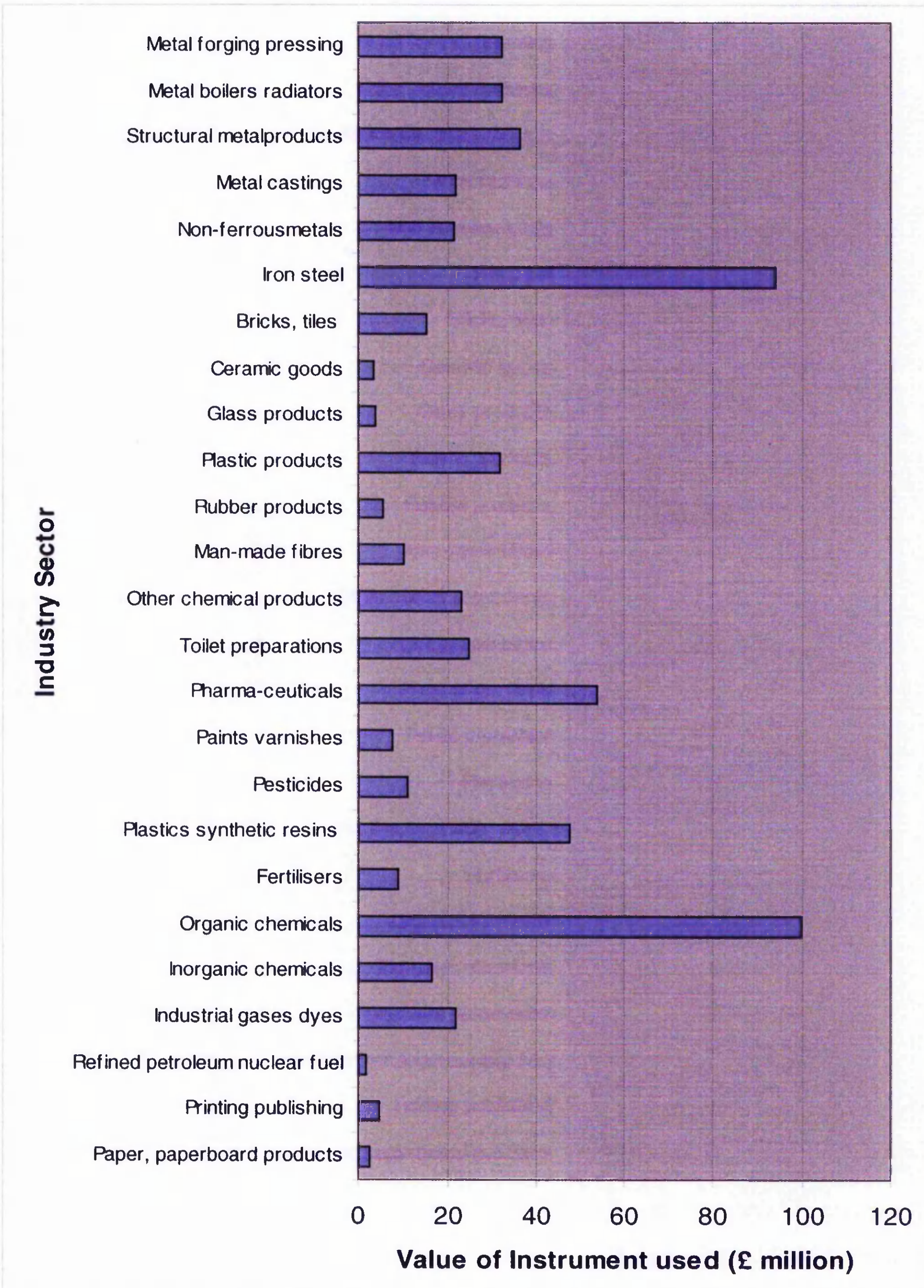
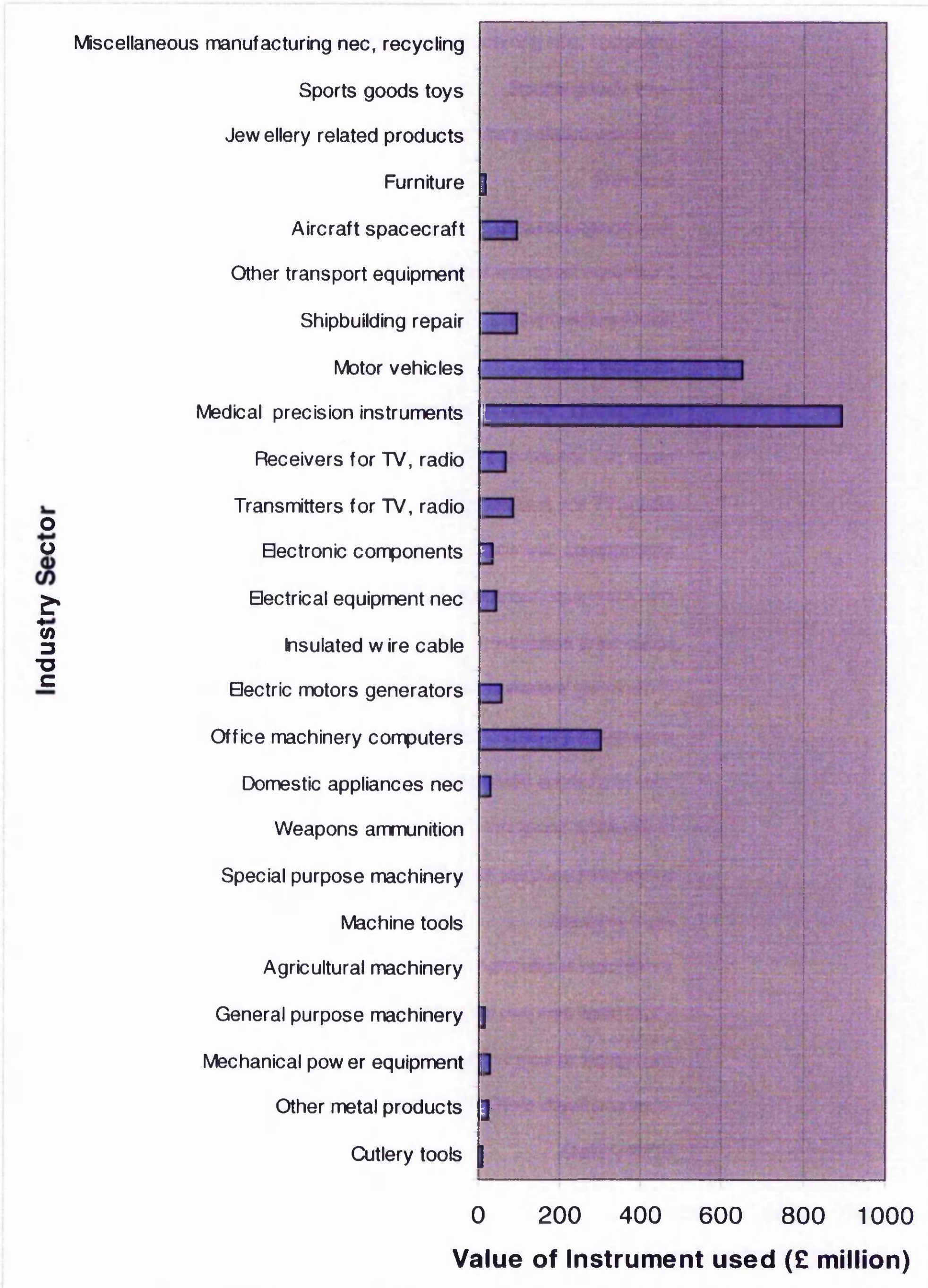


Appendix 2.6 – cont

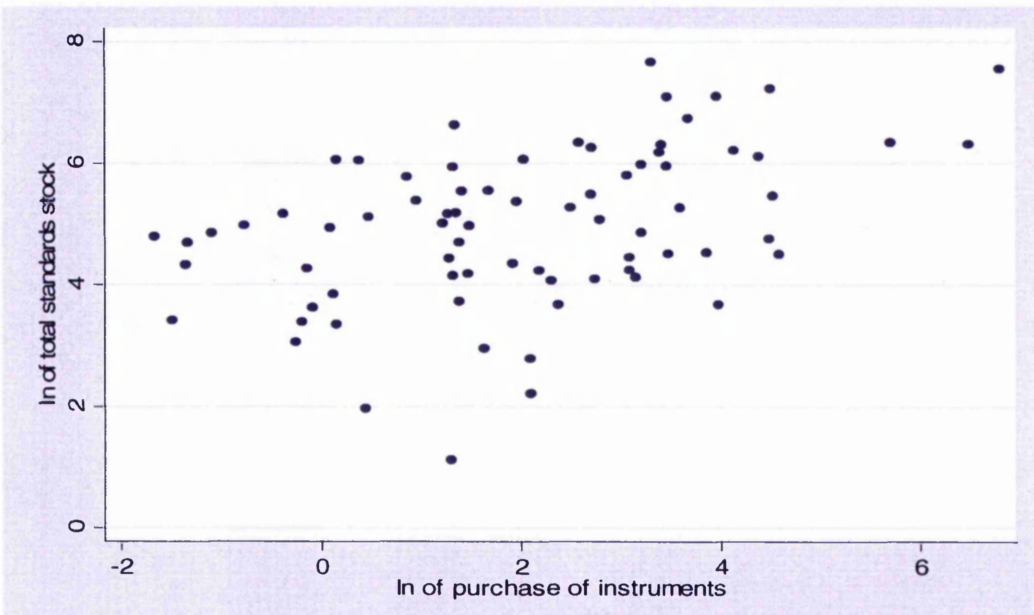


Data Source: Input-output Table, ONS, 2002.

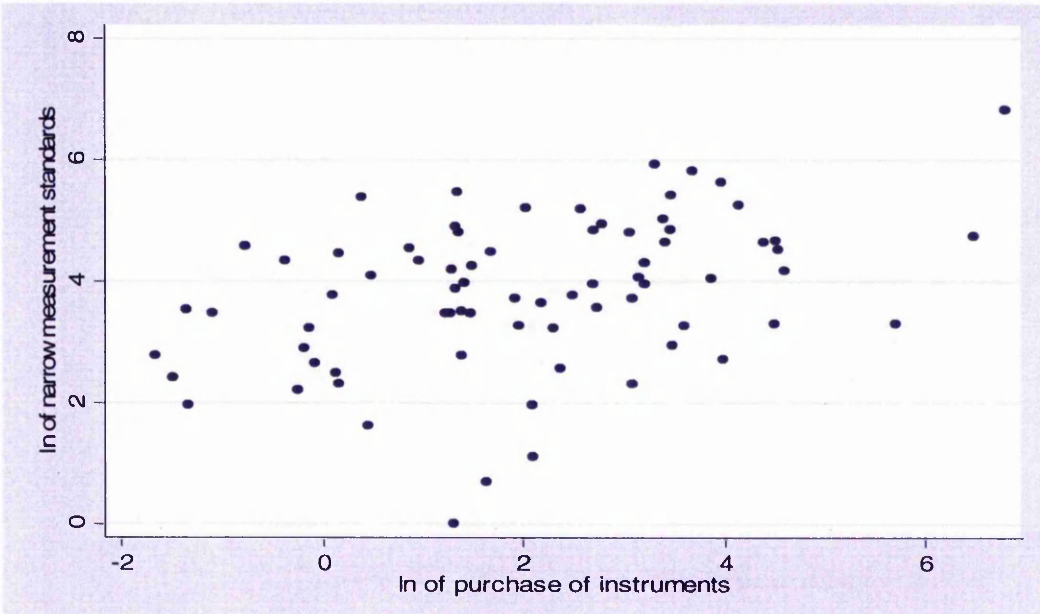
Appendix 2.7

The Comparison of Scatter Charts between the Standards Measure and the Use of Instruments. All numbers are based on natural log scale.

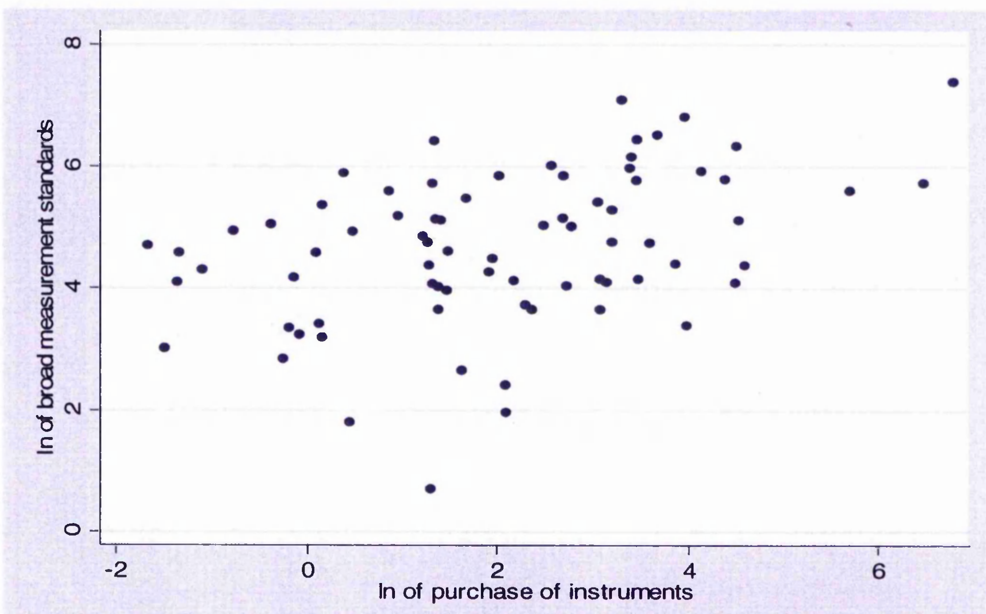
1) The number of total standards stock with the value of purchases of instruments.



2) The number of standards by the narrow definition with the value of purchases of instruments.



3) The number of standards by the broad definition with the value of purchases of instruments



Source: PERINORM Database and ONS, UK

Chapter 3

Measurement, Technology and the Theory of International Trade

3.1 Introduction

The previous chapter investigated the economic role of measurement, and demonstrated how a measurement infrastructure sustains the knowledge processes of technological change, supporting both production and innovation, with implications for international trade. However, the role of technology as an important determinant of international competitiveness in trade was neglected for a long time, with the standard neo-classical model [29] of international trade assuming that countries have access to the same technology. This model prevailed in the literature from the 1940s. Although from the 1960s onwards there have been many empirical studies of the role of technology in international trade, much of this literature lacks a well-defined model (e.g., Krugman, 1995). However the 'new trade theory' emerged in early 1980s, emphasising increasing returns and imperfect competition. Though in the later 1980s, inspired by the 'new growth theory' of Romer (1986) and his followers, a new generation of theoretical models has emerged which gave technological change a more central role in trade theory. The new approach to trade, like the new growth theory itself, is still seeking empirical support (Krugman, 1995).

[29] Neo-classical trade theory has been based on the assumption of identical technological inputs across countries.

The objective of the present chapter is to consider the role of technology, and measurement technology in particular, for trade performance. In general, the public goods effect provided by measurement technology and the associated infrastructure and which helps firms develop more product varieties, emphasises a close relationship between product differentiation and innovation. In order to develop understanding of this relationship this chapter first presents a literature review of international trade studies and secondly, builds upon this discussion to consider the relationship between measurement technology and trade performance.

In general, technology may be thought of as a body of knowledge (techniques, procedures, routines) relating to products, processes of production, and both management and organisational methods in the economic system (Stoneman, 1983). It can however be classified in various ways. The distinction between 'tacit' and 'codified knowledge' has proved useful in the development of the economics of technological change and will be referred to throughout this chapter. Tacit knowledge refers to types of knowledge which cannot easily be written down – 'we know more than we can tell' as Polanyi (1967) described it. Learning to swim or learning to drive are well known examples of types of knowledge which are largely tacit in character. It is widely believed that technological knowledge generally has a large tacit component. This tacit character makes technology difficult and costly to transfer and helps make it function more like a private asset for firms than the public consumption good assumed in some economics literature, notably the HO model discussed below. However, as we saw in chapter 2, codified knowledge must not be ignored. Much of the contribution of metrology to technology in general consists in the codification of scientific and other results and takes the form of accepted standards which are codified as technical documents and underpin the effective functioning of markets.

The neo-classical approach has generally considered technology as codified and freely available knowledge, i.e., as a public consumption good, making diffusion costless and automatic[30]. When applied to international trade theory this means that the set of techniques is assumed to be common across countries because of the perfect diffusion of information; as a result, all countries share the same production function (Wakelin, 1997). However, an

[30] Codified knowledge embedded in journals and books is the standard method of communication in science; and coding is economic because widespread dissemination is intrinsic to science. However, even codified statements involve some tacit elements which are not readily expressible in language, as with the individual skills of a scientist which contribute to the detailed method of an experiment (Metcalfe, 1995).

alternative view of the diffusion process sees technology as being at least partly non-codifiable (tacit) and largely firm specific, making the transfer of technology both a costly and complex process (Nelson, 1992). Thus an innovating firm can obtain a specific advantage from innovation activity. The tacit characteristic of technology emphasises technology as a private capital good, and it is important for firms to retain competitive advantage over its competitors.

As far as technological change is concerned, Schumpeter (1943) classified processes of technological change into three stages. The first stage is the *invention* process, encompassing the creation of new ideas. The second stage is the *innovation* process, encompassing the development of those ideas through to the first commercial marketing or use of a technology. The third stage is the *diffusion* stage encompassing the spread of new technology across its potential market. The major impact of new technology occurs at the diffusion stage and thus the diffusion of technology determines where the welfare benefits lie. In addition, Stoneman (1995) has argued that these three stages are not a linear process in which invention automatically leads to innovation which automatically leads to diffusion. At each stage there is a selection process. Only some new ideas are developed through to the market and only some innovations are successfully diffused. Moreover, there are extensive welfare gains which will be created during the diffusion, and these profits may feedback to the invention and innovation process. Importantly, the expectations of these profits will lead to the development of the technology in the first place, and prior expectations of the returns to particular technologies represent both an incentive to generate and introduce new technologies as well as a major influence upon the directions that technological advance may take.

Schumpeter also drew attention in his writing to the role played by innovation in establishing the competitiveness of firms, asserting that the most important issue for competitiveness is innovation, because the innovative firm will obtain a monopoly benefit by innovation. In addition, Schumpeter (1943) emphasised the importance of non-price competitiveness as follows:

"Economists are at long last emerging from the stage in which price competition was all they saw.(...) But in capitalist reality, as distinguished from its textbook picture, it is not that kind of competition which counts but competition from the new commodity, the new technology, the new source of supply, the new type of organization(...)-competition which commands a decisive cost or quality advantage and which strikes not at the margins of the profits and the outputs of the existing firms but at their foundations and their very lives"

(Schumpeter, 1943, p84)

Thus, as Schumpeter (1943) pointed out, by far the most distinctive feature of capitalist development is the prevalence of non-price competition, i.e., through the development of product characteristics other than price, fostered by research, development, and innovation, to obtain and hold monopoly positions. Moreover, a number of studies have sought to estimate the effects of non-price factors through trade performance, using a variety of indirect measures of quality, including unit values, R&D expenditures, patents and standards and so on. Most studies show that non-price competition appears to play a role at least as important as price competitiveness in explaining market share (Fagerberg 1988; Greenhalgh, 1990; Swann *et al.*, 1996).

Nowadays it has been generally accepted that advantages in technological competence can lead to a better performance in foreign trade (Hughes, 1986). Archibugi and Michie (1998) have more recently highlighted three links between innovation and international competitiveness. First, process innovations reduce production costs and hence output prices, increasing price competitiveness. Second, minor product innovations improve the quality of commodities and make them more appealing in both domestic and foreign markets. Third, major product innovations create, for a limited period of time, a monopolistic position that helps to impose those products in the market, while at the same time bringing in monopoly profits. In the same paper, Archibugi and Michie (1998) also argue that there are advantages for any one country which innovates to a greater extent than its competitors. In the short term, these benefits will translate into a surplus in the trade balance. In the long term, innovative nations will have two main advantages: firstly improved terms of trade and secondly the ability to specialise in whatever proves to be the most rewarding industries. Both of these could prove crucial factors in allowing a nation to achieve higher growth rates.

However, how does technology fit into the existing international trade literature? Figure 3.1[31] below shows a conceptualisation of international trade theory based upon whether differences in technology are determinants of specialisation and trade within alternative trade models. The HO model, the demand side Linder hypothesis and market structure which emphasizes the monopolistic competition model are included within those models where technology plays no role. Those explicitly considering the role of technology can be divided into four main theories:

First, the 'neo-endowment theory'. Developed from the HO model this considers both human capital and knowledge related variables as additional factors of production ('endowments') and seeks to capture the impact of technology on trade flow.

The second category comprises theories based more directly on the implications of technological change. These 'technology theories of trade' consider the technological differences as the main determinant of trade flows. 'Product cycle' models and 'technology gap' models are the two main representatives in this category.

The third is the so-called 'new trade theory.' Based on monopolistic competition, product differentiation and economies of scale, these models help explain international trade between similar economies, contrasting these with the other categories above. The theoretical monopolistic competition model will be discussed in more detail in the next chapter.

Finally there is the 'dynamic comparative advantage theory' typically based on the Ricardian model, which, by assuming only a single factor of production, is able to avoid the factor intensity effects associated with the HO model. In particular the model has been used to examine the effect of 'learning by doing' and R&D on a nation's comparative advantage. Meanwhile, the main difference between 'dynamic comparative advantage theory' and 'technology theories of trade' is that the former emphasizes that innovation is endogenous, leading to 'dynamic' comparative advantage. The technology theories of trade deal with the invention and innovation of new products, stressing the dynamic element to specialisation and the international location of production, and how these change over time.

[31] Dashed lines indicate the model developed from the original.

The structure of this chapter is as follows. Sections 3.2 to 3.5 are overviews of the international trade theories for each of the four categories considered above; i.e., Ricardian, HO and neo-endowment models; technology theories of trade; monopolistic competition; dynamic comparative advantage. In each case empirical work inspired by the theory is discussed as well. Section 3.6 considers the implications of our earlier discussions of measurement technology in the light of these theories, arguing that the monopolistic competition model provides a relevant starting point for modelling purposes. This section develops hypotheses regarding the relationship between measurement technology and international trade using the monopolistic competition model.

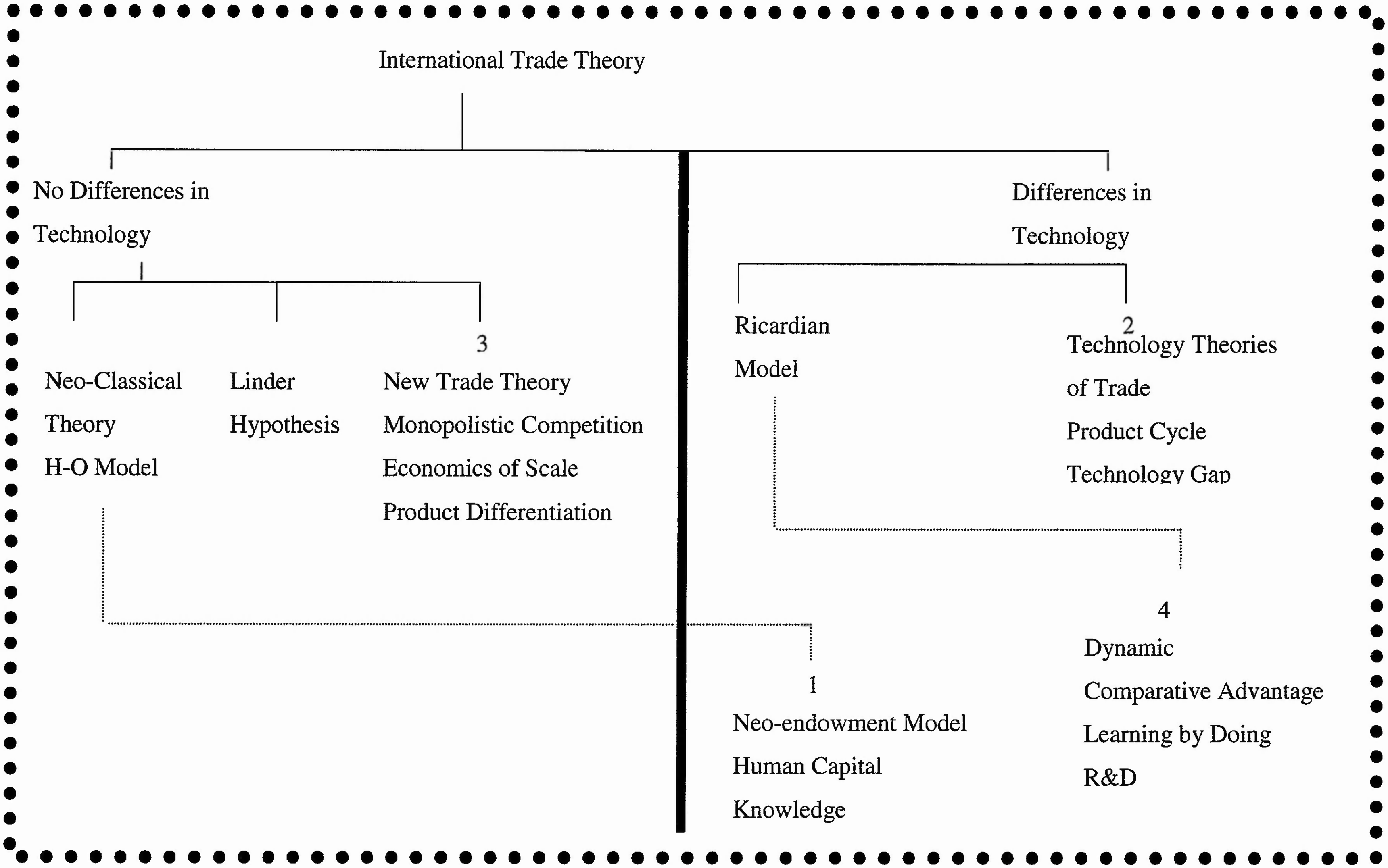


Figure 3.1 A Summary of International Trade Theory

3.2 Comparative Advantage Models

3.2.1 The Ricardian, Heckscher-Ohlin and Neo-endowment Models of Trade

Technology has been viewed as part of trade theory from the beginning, although there has been a long debate as to whether Ricardo's classical example of comparative advantage was based upon differences in a nation's resource endowments or to its technological competence (Archibugi and Michie, 1998). The original Ricardian model implicitly took technology as given, though different, in Portugal and England. The model assumed labour is the only factor of production, creating comparative advantage as a result of relative labour productivity differences. In reality, Ricardo did not explore the reasons for these productivity differences and consequential pre-trade prices, which opened the way for a more explicit consideration of why relative prices differ in the Heckscher-Ohlin (HO) model - named after the Swedish economists Eli Heckscher and his pupil, Bertil Ohlin (Heckscher 1919, 1949; Ohlin 1933), which has been the prevailing theory of international trade since the middle of the last century. Empirical predictions arising from the Ricardian model are considered further however in section 3.2.2 below.

The simplest statement of the HO model considers a two-good, two-factor, two-country model (the so-called 2x2x2 model), and regards comparative advantage between the two countries as being determined by two kinds of differences: differences between countries in terms of their relative factor endowments – their exogenously given supplies of the two factors of production and on differences between commodities in the intensities with which they use the two factors[32]. As in the Ricardian model, factors of production need to be considered mobile within countries but immobile across national boundaries.

In the HO model, factor abundance may be given either a physical or a price interpretation. In the physical interpretation, factor abundance, it is measured (if capital and labour are the two factors) in terms of the ratios between capital stocks and labour forces in two countries. For

[32] Therefore the HO model's another name is factor endowment theory.

example, if the overall capital-labour ratio in the home country is greater than it is in a foreign country, the home country is relatively capital-abundant while the foreign country is relatively labour-abundant. This physical definition can be given as: $(K/L)_{home} > (K/L)_{foreign}$, where K denotes capital stocks and L denotes labour forces. On the other hand, there is an important implication of differences in physical endowments for autarky factor prices. For two countries with identical demand patterns and with access to the same technology, relative factor prices will reflect factor endowments. Thus, the foreign country is relatively labour-abundant if its wage-rental ratio is lower than that in the home country, namely $(w/r)_{foreign} < (w/r)_{home}$ while the home country is capital abundant, where w is the wage of labour and r is the rental of capital.

Factor intensities are defined by reference to the cost-minimizing ratios of the two factors that will be used for the two goods at any common set of factor prices. The production efficiency condition (the cost-minimizing point on a typical isoquant) is where the wage-rental price of capital ratio (w/r) equals the ratio of the marginal products (the slope of the isoquant) as shown in Figure 3.2 point A for industry Y and point B for industry X. Meanwhile, Y_0 and X_0 represent two isoquants for Y and X industries respectively. k_y denotes capital-labour ratio for Y industry and k_x denotes capital-labour ratio for X industries. The Line of K_0L_0 is isocost line, the wage-rental ratio equal to the slope of isocost line[33]. Thus for given factor prices, points A and B determine a unique cost minimizing capital-labour ratio in each industry as measured by the slope of rays OA and OB.

[33] The isocost line is $K = C_0/r - [(w/r) * L]$, where C_0 is fixed amount of expenditure on input K and L at the given prices r and w, respectively.

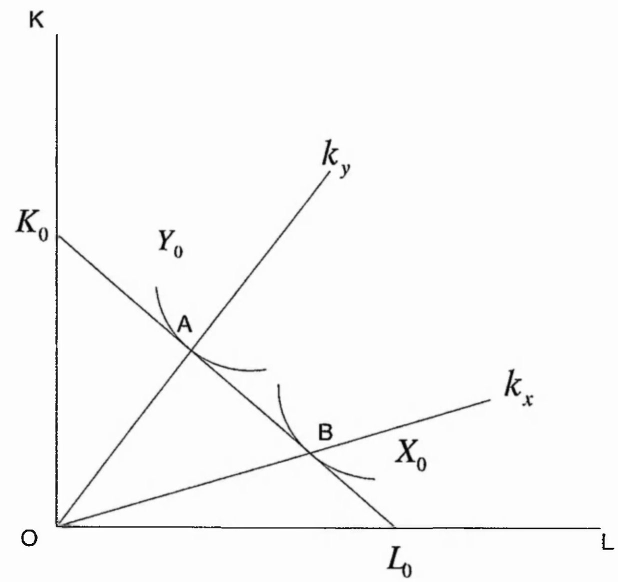


Figure 3.2 Factor Intensities

(Adapted from: Markusen et al., 1995)

The ratio of wages to the rental price of capital (*w/r*) is tangent to the highest attainable isoquant for the condition of output maximization. Thus market-clearing factor prices determine factor intensities. For example, if $k_x = K_x/L_x$ and $k_{y=} K_y/L_y$ denote the capital labour ratios in industry *X* and *Y* respectively, if *ky* > *kx* at those factor prices, *Y* is said to be capital intensive and *X* is said to be labour intensive. Namely, industry *Y* is deemed to be produced by relatively capital-intensive techniques when the ratio of capital to labour employed in its production exceeds that utilised by *X* industry. Under certain assumptions an economy with a higher overall capital-labour ratio (*K/L*) generates a higher wage-rental ratio (*w/r*). This is associated with lower relative prices for the capital-intensive good. If *Y* is more capital intensive than *X* at all common factor price ratios, then we can say that *Y* is unambiguously the capital-intensive good.

It is a matter of some debate which factors of production are most relevant in a two factor two country two good (2x2x2) model. While the typical text-book usually considers them to be land and labour or capital and labour, recent authors have stressed the role of human capital and labour force skills (e.g. Wood 1994, 1998; Wood and Ridao-Cano, 1999; Rowthorn *et al.*, 1997). The issue with capital concerns its tradability. However, once specified, the HO model predicts that the exports of a country should reflect their relative endowments of the two factors, with each country exporting the good which uses intensively its relatively abundant factor. Compare, for example, two neighbouring countries, Japan and China. Let us say that Japan is relatively more abundant in skilled labour (endowment with human capital) and China is relatively more abundant in unskilled labour. Thus these countries trade with each other. The theory leads us to believe that the skill premium on human capital will be lower in Japan leading to a lower relative prices for more human capital intensive products, such as plasma TVs, and other sophisticated orientated products that are made in Japan and exported to China while China will export more labour intensive products such as footwear, clothing and toys.

The key aspect of the HO model lies in the relationship between goods prices and factor prices and which, given the assumption of identical technologies and preferences, is identical for both countries. As Brakman *et al.,* (2006) explain, a useful tool to analyse the relationship between goods prices and factor prices originated with Lerner (1952), namely the Lerner Diagram which is shown in Figure 3.3 and which is drawn in factor space. The two factors considered here are capital and labour. In the context of international trade models, the isoquants in the diagram do not show combinations of capital and labour required to produce given quantities of the two goods, but to produce a given revenue. 'Unit value' isoquants therefore show the quantities of capital and labour required to produce one pound or one dollar's worth of output. A rise in the price of a good results in the isoquant shifting inward, since it will take less capital and labour to produce a dollar of output.

K represents inputs of capital and L represents inputs of labour services. The initial isocost line is C_0. This represents different combinations of capital and labour with the same total costs, given the wage rate and rental rate – the rate at which capital services can be hired. The ratio of these two prices determines the slope of the isocost line[34]. Unit value isoquants represent the production of each good that is worth 1 dollar of revenue when sold in the market. Assuming that there are two goods, TVs and footwear, the price of a TV is P_t and the price of footwear is initially P_{f0}, the firms have to produce only $1/P_t$ units of TV to obtain 1

[34] The iso-cost line shows different combinations of capital and labour that can be purchased at given total cost.

dollar of revenue, as $P_t*(1/P_t) = 1$; and produce $1/P_{f0}$ units of footwear to obtain same revenue, as $P_{f0}*(1/P_{f0}) = 1$. Thus the unit value isoquant for TV is $1/P_t$ and footwear is $1/P_{f0}$[35].

Under the production efficiency condition, the minimum cost combinations of capital and labour for the unit value isoquants $1/P_t$ and $1/P_{f0}$ must be tangent to the same isocost line C_0 at point TV_0 and $footwear_0$, respectively. From Figure 3.3 (a) it can be seen that for given factor rewards, the production of TVs is relatively capital intensive while the footwear is relatively labour intensive.

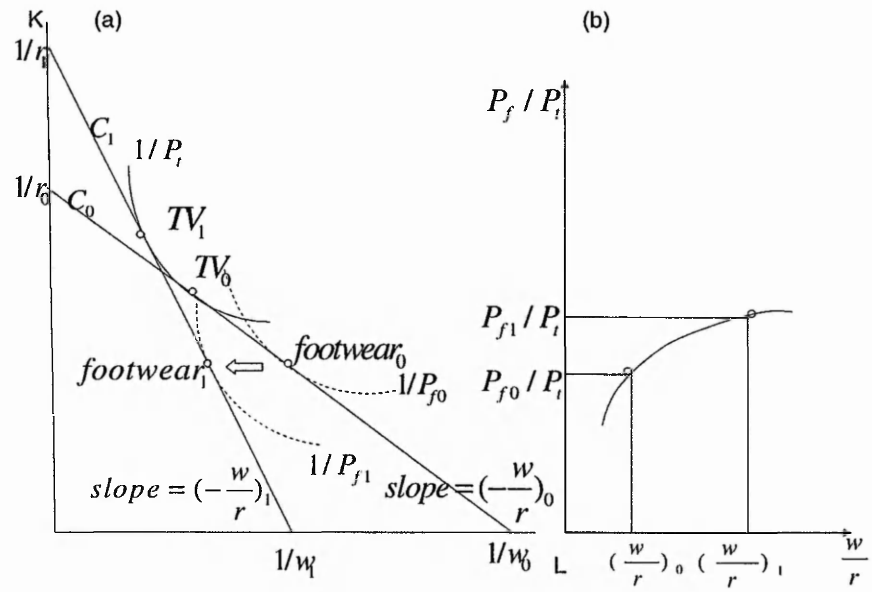


Figure 3.3 (a) Lerner diagram

Figure 3.3 (b) The relationship between goods prices and factor prices

(Adapted from: Brakman et al., 2006)

Figure 3.3 (a) also illustrates what happens if relative good prices change, for example, the price of footwear increases to $P_{f1} > P_{f0}$, which implies that the firms have to produce fewer units of footwear to produce a dollar's worth of revenue. So the unit value isoquant for

[35] Dash line in Figure3.3 (a).

footwear shifts towards the origin from $1/P_{f0}$ to $1/P_{f1}$. As discussed before, the firms produce both goods only if the optimal production points are tangent to the unit isocost line. In other words, this implies that the unit isocost line C_0 must rotate clockwise to the new isocost line C_1, leading to the new optimal production points for TV and footwear which are shown in Figure 3.3 (a) and are labelled at point TV_1 and $footwear_1$ respectively. It can be seen from Figure 3.3 (a), the slope of the unit isocost curve has increased (from slope = $(-w/r)_0$ to slope = $(-w/r)_1$), implying that the wage rate has increased relative to the rental rate. The increase in the price of footwear causes a higher relative and absolute wage rate. Moreover, there is a 'magnification effect' in which a change in the commodity prices is associated with proportionally greater changes in factor prices (Jones, 1965). As shown in Figure 3.3 (a), the initial isocost line C_0 achieves L axis at point $(1/w)_0$ and K axis at point $(1/r)_0$; along with the price of footwear increase to $P_{f1} > P_{f0}$, the new unit isocost line C_1 achieves L axis at point $(1/w)_1$ and K axis at point $(1/r)_1$. Note that the new isoquant of footwear $1/P_{f1}$ represents less footwear than the original isoquant $1/P_{f0}$, so the price of footwear has risen in term of TVs. In addition, the footwear industry is labour intensive and will be associated with a rise in the wage and a fall in rent. This is in accordance with common sense and intuition that a rise in the price of one factor relative to the other is associated with a rise in the price of the commodity that uses that factor intensity. It may also be noted that the wage rate has risen not only in terms of X but also of Y; and similarly the price of capital has fallen in terms of both products. If the price of footwear has risen more than the price of TVs, and footwear is labour intensive, the following results will be obtained, $\%\Delta w > \%\Delta P_f > \%\Delta P_t > \%\Delta r$, where $\%\Delta$ indicate the percentage change.

Figure 3.3 (b) summarizes the discussion on the relationship between factor prices and goods prices. It depicts the link between relative goods price P_{f0}/P_t and the wage-rental ratio $(w/r)_0$, as well as the link between the relative goods price P_{f1}/P_t and the wage-rental ratio$(w/r)_1$. Clearly, there is a monotonic increasing relationship: a rise in the price of labour-intensive footwear raises the wage-rental ratio. Similarly, a rise in the relative price of TVs lowers the wage-rental ratio. The basic prediction of the HO model follows immediately. Under autarky, the relative price of the good which intensively uses a country's relatively abundant factor will be lower, and hence on the opening up of trade, this good will be exported. An important corollary of this proposition is the Stolper-Samuelson theorem (Stolper and Samuelson, 1941). In equalising relative goods prices in the absence of transport costs, trade will raise the price of the abundant factor relative to that of the scarce factor. Moreover, because of the magnification effect discussed above, the real return to the abundant factor will rise and that of the scarce factor will fall. In fact, the establishment of equal relative product prices under trade (with zero transport costs) establishes not only equal relative factor prices, but given the assumption of identical technologies, equal marginal products in both countries – ensuring factor price equalisation (e.g., Chipman, 1966). That HO trade produces powerful impacts on factor prices has made it useful in the political economy of trade, and ensured its continuing relevance for examining the implications of increasing trade between dissimilar economies.

However, there are a number of assumptions which are imposed in the HO factor endowment theory in order to achieve several important predictions about the relationship between economic structure and trade patterns. First, it is assumed that the factors of production are homogeneous between the nations, implying the same quality throughout the world. Furthermore, the factors are in fixed supply to each country, with complete mobility of factors within a country but complete immobility between countries. The other assumptions are that there is the same technology among countries, full employment, perfect competition and constant return to scale and with positive but diminishing marginal productivity of the factors.

Preferences are also assumed to be not only identical across countries but homothetic, implying that the proportions in which goods are consumed depends only upon prices and not upon income throughout the world. This assumption ensures that differences in tastes or in levels of income do not determine the pattern of trade (Bowen *et al.*, 1998). And the final one is with no transportation cost and other trade barriers, commodity prices are equalised throughout the world.

In addition, in view of the formidable logical complexities associated with the theory of international trade and factor prices, it is not surprising that there should have been considerable dispute concerning its interpretation in the light of what meagre data are available. As Chipman states, there are three main assumptions that have been released against the factor-price equalization theorem. First is factor intensity reversal (Pearce and James, 1952; Harrod, 1958 and Johnson, 1957). Second is specialization and, finally, inequality among numbers of products and numbers of factors (Tinbergen, 1949 and Uzawa, 1959). Harrod also advanced the judgment that the number of factors could be expected to exceed the number of products. The final exception was also taken up by Pearce(1959), who concerned himself particularly with the idea that as the number of commodities and factors becomes large, one can expect it to be less probable that all of a country's factor endowments will be sufficiently close together for equalization to result (Chipman, 1966).

Based upon this model, much mainstream applied international trade economics has concentrated on refining this approach of resource endowments and providing empirical tests of the theory. Leontief conducted the first empirical test of the Heckscher-Ohlin theorem in 1953. By using input-output tables for the US and comparing the capital-labour ratio in US exports with those of import competing industries, Leontief showed that the US was exporting more labour intensive goods than it was importing which – on the assumption that the US is a capital abundant economy - contradicts the HO theorem[36] (Leontief 1953). This result came known as the 'Leontief Paradox'. It is worth noting that Leontief himself interpreted the result as not contradicting the basic HO theorem. Instead he used the result to redefine the meaning of factor endowments in the US context, arguing that since labour was much more productive in the US, the economy was actually labour abundant. After Leontief's result was published, a wide range of explanations and empirical studies were undertaken which recast and extended the HO model and created a new development to the international trade theory, such as "neo-endowment theory", discussed next (Sveikaukus, 1983; Hughes, 1986; Courakis, 1991; Maskus *et al.*, 1994).

The most important characteristic of the neo-endowment theory is that it aims to explain trade patterns by recognizing the importance of human capital as one part of a country's capital endowment. In other words, it divided labour into skilled labour (reflecting the accumulation of human capital) and unskilled labour (Courakis, 1991; Maskus *et al.*, 1994). The original two sector model therefore was enlarged to include the third factor of human capital. According to the original factor endowment approach, the country with the larger endowment of skilled labour will have a comparative advantage in the production of skill intensive goods. As well as to emphasize endowments of skilled labour, the most important extension was to include the fourth factor - knowledge - as an endowment to the economy, which could be

[36] Leontief assumed that US had a comparative advantage in capital-intensive goods and therefore will export these goods and import labour intensive products.

used as an input to the production process along with labour and capital, thus maintaining the assumption of a common production function across countries (Stern and Maskus, 1981). Considering human capital and technological factors as additional supplementary issues to determinants of comparative advantage gives the HO model more realism. However, although human capital and technological factors have been considered in the neo-endowment models, there are still inadequate treatments of technology within the theory since both of these variables are viewed as additional *static* endowments in order to explain comparative advantage of a nation, neglecting the endogenous nature of these factors. In the case of Swiss watch making for example, it seems highly likely that the development of these skills is dependent upon prior specialisation in watches. Wood (2007) for example has suggested that this makes the HO model more appropriate at high levels of aggregation, but less relevant for the detailed pattern of specialisation. This raises the question of a dynamic theory of international trade, which is addressed further below.

3.2.2 Empirical Tests of Ricardian, HO and Neo-endowment Models

Empirical Tests of the Ricardian Model

MacDougall was the first to carry out an empirical test of the Ricardian theory in 1951, comparing the average labour productivity in the United States and the United Kingdom for twenty-five manufactured products for the year 1937 (Macdougall 1951, 1952). According to the Ricardian theory, the pattern of comparative advantage between the two countries is determined by a comparison of relative labour productivity (between the two countries) and the relative wage (measured in a common currency), with countries possessing a comparative advantage for all goods for which relative labour productivity exceeded the wage. Given the assumptions of the model, such as perfect competition, each country will specialise in products in which it has a comparative advantage. He hypothesized that at that time, since the American wage rate was approximately twice that of the UK, US firms should have an export advantage in manufacturing sectors for which US labour productivity exceeded twice the level in the UK However, since UK-US bilateral trade at that time was too small relative to each country's total trade and too distorted by tariffs, he had to focus on each country's trade with the rest of the world. At the end he found that 20 of the 25 products satisfied the simple prediction, in cases where US productivity exceeded twice the UK level, the ratio of US exports to UK exports exceeded one, while in other cases the ratio was less than unity. His results are generally taken as providing strong empirical support for the Ricardian hypothesis. MacDougall draws the conclusion that the labour theory of value, crude as it is, does help to provide some explanation of British and American export trade in manufactures in an imperfect world market, reminding us that a country can compete in certain lines, even with a rival whose general level of productivity is much higher (MacDougall, 1952). From the current perspective however, perhaps the most interesting aspect was the size of the differences he found in labour productivities, in part reflecting the different technologies in use.

Productivity is commonly defined as a ratio of a volume measure of output to a volume measure of input use (OECD Manual, 2003). Productivity is closely related to other factors of economic performance, such as the progress of technology, the efficiency of resource allocation and the accumulation of physical and human capital. Therefore, it has been viewed as an important indicator of economic growth. Meanwhile, labour productivity is the most used single factor productivity measure and it is generally defined as an output measure divided by a labour input measure. The labour input measure can be the number of workers, employees or (preferably) hours worked. Some measures may allow for an adjustment for the quality of labour. The output measure can either be the quantity of goods and services (gross output) or the quantity of value added.

In order to analyse the importance of labour productivity, we illustrate an example as follows. In the Ricardian framework, labour is a single input factor of production, under perfectly competitive conditions, with constant returns to scale, the cost (price) of commodity is determined by the cost of the constituent labour per unit of output, and it follows that:

$$\text{Price of a commodity} = \frac{\text{wage rate (per hour)}}{\text{labour productivity (per hour)}} \tag{3.1}$$

where $\dfrac{\text{wage rate}}{\text{labour productivity}} = \dfrac{\text{wage bill/employment}}{\text{output/employment}}$

Assume that there are two countries, the UK and the US, each able to produce two goods, steel and food. Focusing on the steel industry, the price of steel in the UK is,

$$P_{uk} = \frac{w_{uk}}{prod_{uk}} \tag{3.2}$$

where P_{uk} is price of steel in the UK, w_{uk} is wage of steel labour, and $Prod_{uk}$ is steel labour productivity of the UK. On the other hand, the price of steel in the US is,

$$P_{us} = \frac{w_{us}}{prod_{us}} \tag{3.3}$$

where P_{us} is price of steel in the US, w_{us} is wage of steel labour, and $Prod_{us}$ is steel labour productivity of the US .

Assuming that when the price of steel in the UK is lower than in US, $P_{uk} < P_{us}$, according to equation (3.2) and (3.3), the relative wage of UK related to US is less than the relative labour productivity. $\frac{w_{uk}}{w_{us}} < \frac{prod_{uk}}{prod_{us}}$, which implies that the UK has comparative advantage in the steel industry, as shown in Figure 3.4 at column A. Meanwhile, it is assumed that relative wage ratio equal to 2.

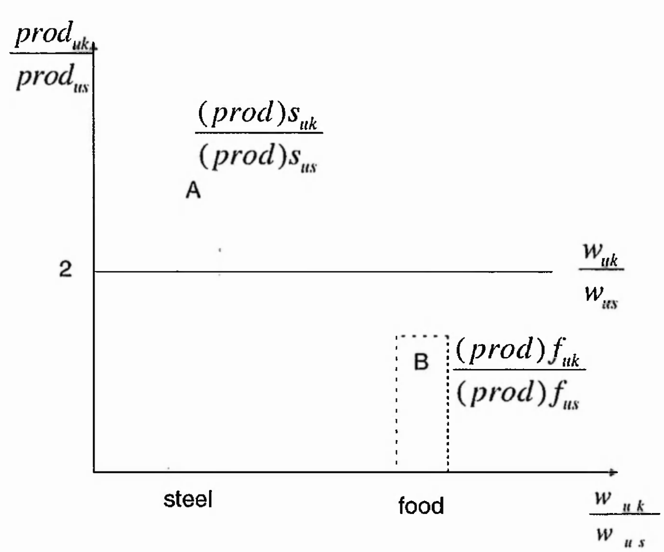


Figure 3.4 Labour productivity and wage ratio

Inversely, at column B in Figure 3.4, $\frac{w_{uk}}{w_{us}} > \frac{prod_{uk}}{prod_{us}}$ for food industry, this implies that the UK has a comparative disadvantage in the food industry. Therefore, the UK and US specialize their production processes according to their comparative advantage, that is, the UK starts producing only steel and the US starts producing only food. The extra production of both steel and food in the world economy can be used, and then both countries gain from international trade. To summarize, the international comparisons of labour productivity made it possible to indicate whether there was a strong relationship between a country's comparative productivity and its trade pattern.

Further well known studies followed: by Stern (1962), Balassa (1963) and MacDougall *et al.* (1962)[37] that use updated datasets but with alternative estimation techniques between the same two countries, UK and US. All the results generally confirmed MacDougall's earlier findings. However, there are also other empirical results that rejected the simple Ricardian hypothesis. One is by Kreinin (1969) who followed similar methods to MacDougall to test three different paired countries, i.e., Canada/Australia, Canada/UK, and US/Canada. Kreinin's various tests did not empirically support the Ricardian hypothesis. Sailors and Bronson (1970), who employed the datasets of 19 countries and 13 manufacturing sectors in 1958, carried out another one. Their empirical results reject the Ricardian hypothesis as well. Bhagwati (1964) also has been critical of the MacDougall study arguing that the methodology employed by MacDougall is without clear theoretical foundation. He suggests that the true test of the Ricardian hypothesis would be to carry out an empirical verification of the relationship between labour productivity and export prices (see, for example, Borkakoti, 1998). Interest in directly testing the Ricardian hypothesis waned after the 1960s although the debate raised some interesting observations about the source of productivity differences between economies, which may be due to substantial and persistent technology differences.

However in recent years many economists have analysed the underlying causes of productivity differences between economies once again (Van Ark, 1990; Crafts and O'Mahony, 2001; O'Mahony and DeBoer, 2002; Matteucci *et al.*, 2005; Inklaar *et al.*, 2005). In particular, O'Mahony has also conducted a series of studies investigating Britain's productivity performance compared with some major European countries, such as France, Germany, and Netherlands as well as with the United States (Crafts and O'Mahony, 2001; O'Mahony and DeBoer, 2002; Matteucci *et al.*, 2005). International comparisons were

[37] Stern(1962) carried out a study by strictly following MacDougall's method by using 1950 data while MacDougall *et al.* (1962) unaware it and produced a study very similar to Stern's study, also using the 1950 data. And both results are very similar. Thus MacDougall *et al.* (1962) suggested that their paper is an addendum to the preceding article by Stern.

usually made in terms of labour productivity, which will be positively influenced by the availability of other factors of production such as the amount of physical and human capital per hour worked. Moreover, comparisons of total factor productivity (TFP)[38] have been widely used as well. Estimates of TFP attempt to identify the component of labour productivity performance that is accounted for not by factor inputs but by the efficiency and technology with which labour is used. This methodology is sometimes called 'growth accounting.'

The economic theory of growth accounting goes back to the work of economists in the early 1940s (Tinbergen, 1942), and independently, to Solow (1957). They formulated productivity measures in the context of production function and associate the measure with the analysis of economic growth. The study made by Maddison (1987) used two steps to estimate the index of joint factor productivity. At first, he established the indicator of labour productivity and capital productivity in country (*h*):

$$\ln(LP_t^h / LP_{t-s}^h) = \ln(Q_t^h / Q_{t-s}^h) - \alpha^h(t,t-s)\ln(L_t^h / L_{t-s}^h) \tag{3.4}$$

$$\ln(KP_t^h / KP_{t-s}^h) = \ln(Q_t^h / Q_{t-s}^h) - (1-\alpha^h(t,t-s))\ln(K_t^h / K_{t-s}^h) \tag{3.5}$$

where Q_t^h / Q_{t-s}^h, L_t^h / L_{t-s}^h and K_t^h / K_{t-s}^h refer to the rate of increase in gross output, labour input and capital input from period t-s to t, while $\alpha^h(t,t-s)$ and $(1-\alpha^h(t,t-s))$ represent the share of labour and capital over the two periods. Maddison assumed that the share of capital is 30% and that of labour is 70% in total. Then he calculated the index of joint factor productivity:

$$\ln(TFP_t^h / TFP_{t-s}^h) = \ln(Q_t^h / Q_{t-s}^h) - \alpha^h(t,t-s)\ln(L_t^h / L_{t-s}^h) - (1-\alpha^h(t,t-s)\ln(K_t^h / K_{t-s}^h) \tag{3.6}$$

Equation (3.6) provides a useful measure of productivity growth regardless of the functional form of the production function. Importantly, output growth can be decomposed into various

[38] In the two factor case, a total factor productivity index is derived from the quantity of value added divided by joint inputs of capital and labour, combining measures of labour productivity and capital productivity weighted by factor shares. In a many factor case, the index is derived from the difference between (gross) output and an index of inputs, using factor shares as weights.

components such as labour, capital and TFP. In addition, Van Ark (1996) and Jorgenson (1995) argued that there are important differences in TFP across countries, hence, given quantities of inputs, nations will produce different amounts of output. The implication of this is that the two standard assumptions in neo-classical trade theory are rejected: technological knowledge is not the same in all countries and production processes do not exhibit constant returns to scale. Growth accounting indicates that both capital accumulation and improved technology are generally important determinants of labour productivity.

In addition, most of recent series of empirical work have found that information and communications technology (ICT) can be viewed as a driver of British productivity differences between the US and Europe. O'Mahony and DeBoer (2002) showed that the impact of ICT on labour productivity growth can come through two channels. The first is the direct impact of investments in this type of equipment on output per hour worked. The second is through TFP growth-spillovers or external benefits of the new technology which can raise underlying productivity (Jorgenson and Stiroh, 2000; Stiroh, 2001; Oulton, 2001). Moreover, analysis of the proximate determinants of relative productivity performance indicates a notable difference in the sources of the productivity gap: between the UK and the US on the one hand, where innovation plays the major role; and between the UK and European countries, where a measure of broad capital, including both investment and skills, is more important (Crafts and O'Mahony, 2001).

Furthermore, the estimation of relative labour productivity levels also has been focusing on sector levels. O'Mahony and DeBoer (2002) found that US productivity advantage over the UK is largely driven by three sectors, the distributive trades[39], manufacturing and financial and business services. The gap is considerably smaller in construction and transport and communications, and the two countries have about equal productivity in personal services. The French labour productivity advantage is mainly due also to these three sectors, with financial and business services having a somewhat smaller impact. The German productivity advantage over the UK is driven by a lead in manufacturing and financial and business services sector with little contribution from the distributive trades.

[39] Distributive trades correspond to the wholesale and retail trade; repair of motor vehicles, motorcycles and personal and household goods. It includes the following Divisions: Sale, maintenance and repair of motor vehicles and motorcycles; retail sale of automotive fuel; Wholesale trade and commission trade, except of motor vehicles and motorcycles; and retail trade, except of motor vehicles and motorcycles; repair of personal and household goods (OECD, 2008).

Empirical Tests of the HO and Neo – endowment Models

Many empirical tests have focused on testing the HO hypotheses. Some of the more important studies are discussed in this section.

The pioneering work of empirically testing the Heckscher-Ohlin model was by Leontief in 1953 that brought about the famous 'Leontief Paradox' (Leontief, 1953). He employed the input-output tables for the United States in 1947 to compute the amounts of labour and capital used in each industry. In addition, he utilized US trade data for the same year to compute the amounts of labour and capital used in the production of $1 million of US exports and industries competing with imports. Leontief had assumed that the US had a comparative advantage in capital-intensive goods and therefore that the US would export these goods and import labour intensive products. However, the empirical evidence showed that the US was exporting more labour intensive goods than it was producing in import substitution industries, which contradicts the HO theorem. This is the Leontief Paradox.

Numerous attempts were made subsequently to verify Leontief's results for the US and extend the approach to other countries with mixed results. Following Leontief's methodology, Tatemoto and Ichimura (1959) analysed the data of Japan in 1951 and found no paradox. But Bharadwaj (1962) studied the bilateral trade between India and the US in 1951 and showed that this produced another Leontief type paradox. It is worth noting the study by Baldwin (1971), who was the first to consider human capital as an alternative explanatory factor for trade. The study used the 1958 input-output table and 1962 international trade dataset to compute the direct and indirect factor requirements per million dollars worth of US exports as well as competitive import replacements for 64 sectors. The results showed that the 'paradox' was still strongly in evidence. However, if the human capital-labour ratio alone was considered then the paradox did not exist, while the further factor of natural resource industries also improved the results. Stern and Maskus (1981), using both regression analysis and Leontief-style input-output techniques for US trade for 1958 and 1972, had found a negative relationship for physical capital in 1958 upholding the Leontief Paradox, although the later study (in 1972) found that US exports were relatively intensive in physical capital and therefore that the Leontief Paradox was no longer being observed. Moreover, the negative relationship for physical capital in 1958 disappeared when the natural resource industries were excluded from the model. In addition, they found skill variables to be of significant importance in explaining the comparative advantage of the US.

Research in the last two decades has continued to consider the empirical implications of the HO model, many developing and expanding the basic model. For example, the Heckscher-Ohlin-Vanek theorem - the noteworthy extension made by Vanek in 1968 - also named the 'factor content' version of the HO model (or HOV model) translated the predictions of the HO model into a multi-factors, multi-commodities and multi-countries framework. The algebra of Vanek's model can be derived as follows[40] for a world where there are at least as many goods as factors:

Let index l denote the factor of production ($l=1,...L$), index i indicates the final good ($i=1,...N$) index h the country ($h=1,...H$), P_i the price of good i. $\boldsymbol{V^h}_l$ is the available endowment of factor l in country h. $\boldsymbol{X^h}_i$ the production level of good i in country h. Technology can be represented by letting α_{li} denote the cost-minimizing input requirement of factor l in the production of one unit of good i. Following the usual HO assumption, it is assumed that the production technology is the same for all countries in the world. Moreover if factor prices are equalised, then α_{li} is the same in every country.

If input l is fully employed, the sum of the use of factor l for all goods, which is equal to the unit input requirement times the production level, must be equal to the endowment

$$V_l^h = \sum_i a_{li} X_i^h \qquad (3.7\text{ a})$$

Where the bold notation indicates a vector or matrix, appropriated defined. Thus,(3.7 a) can be expressed in matrix form as

$$\boldsymbol{V^h} = \boldsymbol{A}\ \boldsymbol{X^h} \qquad (3.7\text{ b})$$

where $\boldsymbol{V^h}$ is an I x 1 column vector representing factor use, A is an I x J square matrix indicating the cost-minimizing technology, and $\boldsymbol{X^h}$ is a J x 1 column vector representing the production structure of the economy.

[40] The discussion here is based on that in Brakman *et al.*, 2006.

Since demand is identical and homothetic in the basic HO model, country h's share in world consumption of each good i is proportional to its share in world income, s^h ,

$$C_i^h = s^h C_i^{world} \qquad (3.8\ a)$$

or

$$\boldsymbol{C}^h = s^h \boldsymbol{C}^{world} \qquad (3.8\ b)$$

where $\boldsymbol{C}^h_i$ denotes the consumption level of good i in country h.

On the global scale, world production is equal to world consumption $\boldsymbol{C}^{world}=\boldsymbol{X}^{world}$. Using the fact that trade is assumed to be balanced for each country and that the exports of a country are equal to production minus consumption, this gives for each country:

$$T^h = X^h - C^h \qquad (3.9)$$

where $\boldsymbol{T}^h$ is a column vector representing exports of the i goods for any economy h. Pre-multiplying equation (3.9) using the technology matrix A, labelling the result $\boldsymbol{F}^h$ and using the above equations (3.7b), (3.8b) and (3.9), the following expression is obtained:

$$F^h = AT^h = AX^h - AC^h = V^h - s^h AX^{world} = V^h - s^h V^{world} \qquad (3.10)$$

The components of the column vector $\boldsymbol{F}^h$ on the left-hand side of equation (3.10) are the factor contents of net exports for each of the i goods. The final expression on the right hand side of equation (3.10) shows that this vector equals the deviation between a country's supply of factors of production and its GDP equivalent share of the world total. For a positive value for factor l, we say that the country is relatively abundant in factor l. According to equation (3.10), the factor content of its export flows must then also be positive.

The HOV model has a bearing on the Leontief Paradox, since the more recent heavy criticisms of the Leontief methodology are based on the HOV model, such as Leamer (1980). In his paper Leamer presents a devastating critique of Leontief's empirical procedure and shows that a country cannot be revealed to be a relatively capital-abundant country if capital embodied per unit of labour in exports is greater than that in imports. He states that if a country is capital abundant, then the capital/labour ratio embodied in production must exceed the capital/labour ratio embodied in consumption. Furthermore, Leamer argues that the methodology of Leontief was not valid with non-balanced trade, and in 1947 the United States had a trade surplus and was exporting both labour and capital as embodied in trade.

Bowen *et al.* (1987) carried out another well cited study, which provided a more complete test of the HOV theorem. They used the HOV model which equates the factors embodied in a country's net trade to the country's excess factor supplies, in a multi-country, multi-factor and multi-commodity framework. They considered 27 countries and 12 factors of production, using 1966 data for supply of 12 resources for each country. They then computed the total amount of each factor embodied in 1967 net exports of each country. They found that their results did not support the HOV model of an exact relationship between factor contents and factor supplies. As a result, Bowen *et al.* (1987) concluded that the assumption of common technologies across countries is particularly inappropriate. In line with this result, more recent work using the HOV approach developed an extended version of the HOV model that allows for different technologies across countries. The contributions by Trefler (1993, 1995) have been particularly influential.

Trefler successively introduced two ways of allowing for technological differences within the HOV model, providing a landmark in this field of empirical study. In his first study, he allowed for all factors in every country to differ systematically in their productivities with the only exception to this being the United States, which he uses as the 'benchmark' country with factor productive normalised at unity. Then he used the data of 33 countries and 10 factors of production, i.e., capital, cropland, pasture, and seven categories of labour for the year 1983, obtaining strong empirical support for the modified HOV model, which allowed for factor-augmenting international technology differences and the implied international factor price differences. The calculated international productivity differences make the HOV theorem perfectly fit the data on trade and endowment (Trefler, 1993). In Trefler's second study (Trefler, 1995), he puts forward two puzzles. The first is "the case of missing trade": the measured factor content of trade of many countries is found to be very small, and much smaller than what their endowments would predict according to the HOV model. (In Trefler's data, the variance of measured factor content of trade is found to be 0.032 of the variance of HOV predicted factor content of trade). The second is "the endowment paradox": poor countries are revealed to be abundant in most production factors and rich countries are revealed to be scarce in most production factors (in Trefler's sample, the number of abundant factors is negatively correlated with GDP per capita at -0.89). He then developed alternative hypotheses in terms of technology differences and consumption differences in order to explain the deviations from the HOV theorem. In summary, he found that the international technology differences hypothesis does a good job of fitting the data for 1983. In summary, the important contribution by Trefler (1993, 1995) lay in loosening the assumptions of the HOV model, and most importantly in allowing for differences in technology; it generally improves the empirical valid proposition of the model. More recently, Davis and Weinstein (2001) followed the same approach as Trefler to generalise these technological differences and further explain how to account for the differences between the factor content of trade and relative endowments, and yield results which strongly support the HOV model.

To summarize, the HOV model explains international trade as the international exchange of the services of factors of traded goods. This is an extension of the HO theory, from a two-factor model to an *n*-factor model. The HOV theory shows that, if trade is balanced, countries will have an embodied net export of factors in which they have an abundant relative endowment and a net import of factors in which they have a scarce relative endowment, where abundance and scarcity are defined in terms of a factor-price-weighted average of all resources (Widell, 2004). However, under empirical testing, the HOV model performs quite poorly, unless the assumption of identical technologies across countries is abandoned. In other words, we have to accept that the HOV equation can fit perfectly by allowing for sufficient differences between technologies across countries. This brings us back to the Ricardian model where technological differences are a major determinant of trade patterns. But such technological differences are very difficult to be accepted as exogenous which increases the need for the exploration of explicit models of technological change and trade.

In addition, the HO model has noticeably become fashionable again, after a long decline with prolonged attacks by the new-trade theory. As Wood (2007) has argued, there are three misunderstandings of HO theory which have caused unfavourable empirical results. The first echoes what Trefler and others had concluded from the studies cited above, the confusion between relative and absolute magnitudes. The HO theory effectively emphasizes relative factor endowments. However, much empirical work, especially that based on the Vanek reformulation, examined relationships between absolute magnitudes which depended on the implicit assumption that all countries have the same levels of technology. Secondly, as mentioned above, it has been working at the wrong level of aggregation. Wood suggests that HO works best at a high level of aggregation, with a few broadly defined goods, for example, primary products[41], labour-intensive manufactures, and a few broadly defined factors that are used in all sectors, for instance, labour, land and skill. The third issue concerns the treatment of capital as a factor of production. Wood stresses that since most capital is internationally mobile, it does not fit the assumptions of the HO model, which is based upon the presumption that factors are internationally immobile.

In other work Wood has also asserted the relevance of HO models in relation to the development of North-South trade in recent decades (Wood 1994), especially to its impact on wages and employment in the world economy. There are two geographical areas ('countries'): 'North' (the developed countries) and 'South' (developing countries); two factors (skilled and unskilled labour) and two goods (skill-intensive and labour-intensive manufactures). Wood assumed that both the North and the South have the same technology, but they differ in their labour endowments, the proportion of unskilled labour being much higher in the South. Under autarky, the relative price of the labour-intensive product is much higher in the North, and the relative wage of unskilled labour in the North is also much higher. However, reduction of barriers to trade has caused the North to specialise in the skill-intensive good, reducing the demand for unskilled workers, and vice verse in the South. Within each country, the gains from this expansion of trade accrue to the abundant factor, while the scarce factor becomes worse off. In the South, expansion of labour-intensive production increases the demand for unskilled workers and hence raises their wages, while the demand for (and wage of) skilled workers falls. This decreases income inequality, because it reduces the wage differential between higher-paid skilled workers and lower-paid unskilled workers. In the North, conversely, skilled workers become better off and unskilled workers worse off, which increases income inequality. In addition, unlike the traditional Heckscher-Ohlin model, Wood does not assume that each region continues to produce some of both goods; if the differences in factor endowments between North and South are as great as they are, each area will stop producing the other's speciality altogether. In other words, the North produces only skill-intensive goods, the South only labour-intensive goods. With complete specialization, there

[41] Commodities produced by the extractive industries such as farming, fishing, forestry, and mining.

will of course be no factor price equalization. Thus, Wood argues that complete specialization along with transport costs and differences in infrastructure capital will lead to a narrowing of the skilled-unskilled wage ratio in the South and a widening in the North (Wood, 1994). Although a heated debate has been aroused by Wood's work, Singh argues that Wood presents formidable arguments and evidence to challenge this conventional wisdom[42] (Singh, 1995).

Turning to the empirical evidence for the neo-endowment model, most technology variables introduced into the factor endowment model have generally shown the importance of innovation in influencing the trade pattern of the United States. The following studies use econometric methodology to investigate the relationship between technology variables and trade performance. The work by Gruber *et al.* (1967) was the first time an empirical link was established between export performance and R&D using US 1962 data for 19 manufacturing sectors. They found that the five industries with 89% of the economy's total R&D expenditure accounted for 72% of US exports of manufactured products. R&D was measured by personnel as well as by expenditures. As Gruber argued, when the five industries with the highest research effort are separated from the other fourteen industries, it begins to grow clear that the export strength of US industries is centred in the group of five (Gruber *et al.,* 1967). Work by Keesing (1967) considered 18 US manufacturing sectors, employing a measure of R&D intensity (using scientists and engineers in each sector's R&D activity as a percentage of the sector's total employment in 1961). Keesing's work strongly confirms a significant positive correlation between R&D intensity and manufacturing export performance. Stern and Maskus (1981) found technology as measured by R&D expenditure as a percentage of industry value added to be of considerable importance in explaining the comparative advantage of the US in 1970. In addition, Stern and Maskus (1981) also used the number of engineers and scientists as a percentage of total industry employment measure for R&D in 1960 and 1970, with both years showing a positive and significant impact from R&D on US net exports. For the UK, Hughes (1986), using R&D expenditure as a ratio of value added to capture the effects of technology on trade, found that it had a positive and statistically significant impact on manufactured exports.

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[42] Most mainstream economists have generally denied some unfavourable consequences of North-South trade, e.g., rise in unemployment, real wages have not increased, etc.

However, although neo-endowment models which contain a variety of proxies for technology factors yield quite successful results in explaining trade flows, it needs to be acknowledged that technology that can be produced through investment in research and development (R&D) expenditure is (as with other factors such as capital and human capital which can all be accrued over time) endogenous in the long run. The endogenous nature of these factors of production raises the question of the evolution of comparative advantage, and the ability of a country to create a comparative advantage through policy measures.

3.3 Technology Based Theories of Trade

3.3.1 Concepts of the Products Cycle and Technology Gap

The restrictive nature of the factor endowment theory and the need for its development or even replacement became clear and acute following the publication of Leontief's pioneering research (Leontief 1953, 1956). Quite apart from the development of neo-factor endowment models, an increasing number of researchers began to consider other aspects of technological difference as a main determinant of trade flows. Two key ideas that were introduced during the 1960s were those of 'technology gaps' and 'product cycles'. In the resulting models, technological innovation itself – rather than endowment - is central in explaining trade patterns.

One of the first economists who addressed the issue of how technological change can influence patterns of trade was Posner (1961) with his 'technology gap' theory. In Posner's model, the innovating country gains a temporary advantage in the manufacture of a particular product because of time lags in the diffusion of knowledge internationally. Posner called the time taken between the innovation and its imitation in the partner overseas the 'imitation lag'. The imitation lag is relevant for trade when it is longer than the time taken for consumers in the partner country to be willing to pay for the innovation – the 'demand lag'. In other words, there is a temporary advantage through the development of new products and processes, and for a period of time the country that is host to a particular invention or innovation will have a technological lead over its trading partners. Effectively this is a situation of absolute advantage and temporary monopoly. Therefore the innovating country will be able to export the goods concerned even though it may not have an apparent comparative advantage in terms of being well endowed in the factors used intensively in the production of that class of goods. After they are imitated by competitors, the temporary advantage will be lost. However, since the innovating county has technical superiority, the technological leader may be able to continue to innovate and maintain an advantage from new products. Posner draws attention here to potential technological complementarities or other reasons for 'clustering' of innovations. Why should the original innovator be more likely to innovate again? Let us say an automobile designer developed a new more powerful engine for a new sports car. An engine is only a part of the car and he/she and the design team have to carry on to develop lighter/stronger materials for the chassis, a more efficient brake system and better tyres, etc., to make a complete package in order for it to work commercially. Therefore, continued innovation is an important strategy allowing the innovator to face possibly lower cost competition.

The technology gap theory suggests that the innovating country has both an absolute advantage and a temporary monopoly in trade until such time as the other country imitates it. Deardorff (1984) argued that this model might be compatible with the theory of comparative advantage as the innovating country has a comparative advantage in innovative products.

Distinct from the technology gap theory, Vernon (1966) set up a 'product cycle' hypothesis, where again innovation leads to trade. Vernon suggested that new products pass through three different phases: i.e., an *innovation*, *maturing* and *standardisation* stage of their life cycles. At the first stage, more sophisticated technology and a sizeable chunk of Research and Development (R&D) expenditures are required to produce goods but only the few wealthiest nations have such ability. In his original paper, this nation is restricted to the US, but extended to other countries in later work (Vernon, 1979).

At the innovation stage, new products are 'knowledge intensive', the higher price of the product restricting consumption and the lower output, and production remains in the innovating country. This is because there is as yet no dominant design and the producer will seek to be as close to the consumer as possible to receive feedback about the product, in the nature of the generation of 'tacit' knowledge, as discussed above. The second stage is that of a 'maturing' product. At this stage, along with the product being copied by producers in other countries, the degree of competition facing the innovating firm both at home and abroad has increased. The product begins to be imported. The third stage is where the product technology has been standardized. At this stage, producers are looking for the lowest cost location for producing the product since both technology and capital have gradually lost their importance and unskilled labour now becomes the important input. The standardization permits technology transfer and relocation of production through international investment to low wage economies. Consequently, the developing countries become the main producers because of their cost advantages in production. As a result, production in the innovating country and other industrialised countries begins to fall. Exports from the innovating country decline and imports increase until eventually the innovating country becomes a net importer of the product.

In general, the model of product cycle provides a framework for the conceptualisation of technological innovation and its international diffusion. However, there are still deficiencies in the product cycle model which has stimulated criticism, such as Walker (1979) who criticized the product cycle model's emphasis on technical stability, and the standardization of production. For example, nowadays many large multinational companies have already relocated many of their manufacturing facilities to developing countries because of cost advantages, implying that they have the capability to shift the final stage in the production of many goods at an even earlier stage in the cycle. However, where the rate of product innovation is rapid, products may never reach the standardisation or even maturity phase. Improvements to the product may mean that the technological lead remains with the innovating country for an indefinite period of time (Wakelin, 1997).

In the development of the trade literature, Krugman produced theoretical papers which formalise the ideas of both product cycles and technology gaps. Krugman (1979) reframed the 'product cycle' model. There is only one factor of production, labour. All products are produced with the same production function. This ruled out any factor proportion motivated trade according to differences in labour productivity. However, there is a distinction between 'new' goods, where for unspecified reasons, the 'North' has a monopoly, and 'old' products which can be produced anywhere. In practice however, since new products are also demanded in the non-innovating 'South', a wage premium in the North means that old products are only produced in the South. North therefore only produces new products, because of its higher costs in the production of 'old goods' – goods for which the technology has diffused to the South - not because of productivity disadvantage but because wages in the South are lower. In the model, new goods become old goods as the technology for producing new goods gradually transfers to the South. Because of this gradual transfer of technology new industries (products) need constantly to emerge in the North in order to maintain its relative wage premium, the new industries declining and disappearing sooner or later in the face of low-wage competition from the South. North's higher wages therefore reflect the rent on the North's monopoly of new technology (Soete, 1987).

In Krugman's (1990) technology gap model, labour is again the only factor of production. There are two regions, namely North and South, which can be ranked by their technological level and goods which can be ranked by technology-intensity. Moreover, the North is the more advanced region while the South is less advanced. Thus the trade pattern reflects an interaction between countries and goods. Technologically advanced countries have a comparative advantage in technology-intensive goods. One of the outcomes of the model is that technical progress in an advanced country, which widens the technological gap, opens up greater opportunity to trade, which in turn raises real income levels in both countries, whereas 'catch up' by a follower tends to hurt the leader by elimination of gains from trade. On the other hand, with Southern catch-up, production migrates South, raising demands for Southern labour. As a result, the South's wage rises relative to the North's wage. Hence, the terms of trade must improve in the South while deteriorating in the North. It further implies that the North may be harmed by Southern catch-up.

To summarize, both the technology gap and product cycle theories emphasise the importance of differences in technological knowledge in accounting for the inter-country product pattern of trade. Both stress the importance of the timing of the introduction of a new technology in influencing where each good is produced, one because the diffusion of technology takes away the first country advantage, and the other because the characteristics of the product change over time, influencing the optimal location of production. Moreover, both the technology gap and product cycle theories have been a source of inspiration for later theoretical and applied work ever since. One strand of research analyses technology gaps in the international economy from Schumpeterian perspective (e.g. Dosi *et al.,* 1990), another based on "new trade theory" focuses on the role of economies of scale, product differentiation and externalities as a source of technology gaps and specialization (Krugman, 1990) .

3.3.2 Empirical Tests of the Technology Based Theories of Trade

As we noted above, Posner (1961) and Vernon (1966) created benchmark models. Numerous empirical studies have focused on the applicability of these models. Hufbauer made significant contributions (Hufbauer 1966, 1970). In the earlier work he analysed the leads and lags of innovation in synthetic materials ranging from neoprene rubber, polythene, etc., to acrylic, viscose, rayon, etc. His results support the pattern of trade based on the creation and diffusion of new technology (Hufbauer, 1966). In his 1970 paper, he used the trade data for 24 countries to test the product life cycle and technology gap theories from which he developed a specific tool: measuring the 'first trade dates'[43]. He found that the measure of first trade dates captures the temporal dynamics of the trade theory (Hufbauer, 1970). Branson *et al.* (1971) have used this method to capture the effect of new products on US trade in a regression analysis of comparative advantage in manufactured goods, and have agreed that the first trade date is a significant explanatory variable (Branson *et al.*, 1971).

Many other empirical tests of the technology gap theory confirm the important role of technology in explaining trade performance. In general, as measures of technology, there are two main proxies in most of the empirical works. R&D expenditure, the number of scientists and engineers employed in the R&D sector, indicate the input into the innovation process while patents provide a measure of innovation output. In a more recent example, Verspagen and Wakelin[44] (1997) investigated the determinants of competitiveness in a study of sectoral bilateral trade flows between nine advanced OECD economies, using R&D intensity measured by R&D expenditures as a fraction of value added. They found that there are four

[43] The US Census Bureau's export classification list, "Schedule B" which published in 1909, 1915,1919,1921,1922,192,1928,1929,1930,1931,1932,1933,1938,1939,1941,1944,1949,1952,1955,1958 and 1965. Each new edition expanded the list of commodity heading, so this expanded from a small pamphlet of 100 pages in 1909 to a heavy volume of 1,000 pages in 1965. It provides the data for dating the arrival of new products to the status of internationally trade goods. According to this list, Hufbauer computes the first-trade dates of each of the seven-digit Standard International Trade Classification (SITC) category by taking the unweighted average of the dates of products in each seven-digit category, and then computes the first-trade dates on the three-digit SITC basis by taking the unweighted average of the seven-digit values (Hufbauer,1970).

[44] Verspagen and Wakelin's work based on the neo-Schumpeterian approach. The neo-Schumpeterian approach has also emphasized differences in technology as an important motivating factor for trade. However, unlike the neo-endowment theory of trade – which viewed technology factor as additional factor of production which neglected the role of the accumulation and the diffusion of technology. The neo-Schumpeterian approach considered technology as an endogenous factor, it embody specific, non-codifiable and only partly appropriable knowledge. As Wakelin (1997) argued that most innovations are incremental improvements on existing innovations which based on past experience. They are frequently specific to the firm, and based on firm-level skills and learning. At the macroeconomic level these firm-specific advantages translate into a competitive advantage for the country.

sectors where the R&D parameter is negative and significant - in food, textiles, refined oil and aerospace, but others where the coefficients of 10 sectors - wood, paper and publishing, chemicals, pharmaceuticals, rubber and plastic, ferrous metals, fabricated metal, machinery, electrical machinery, and motor vehicles are positive and significant, as expected. They draw a conclusion that the results provide support for a technology-interpretation of trade, although there are a number of sectors for which the sign of the R&D variable is contrary to expectations, or insignificant. On the other hand, there is work which considers technology output rather than technology input to measure the technology gap theory. This follows Soete (1981) who argues that technology output in the form of 'patents' is more appropriate for capturing the role of innovation, and Dosi *et al.* (1990) who, based on a cross-country regression analysis for a single year found that, of the 40 industries examined, about half were influenced in their direction by technological specialisation (measured by the use of US patents) in the same industry, apart from two types of industries[45]. This evidence suggests that the technology variable is important in explaining the export performance in a larger number of industries. Amendola *et al.* (1993) also use patents as the innovation variable, but in conjunction with country level time series data, they found significant long run effects of the patent on sixteen industrialized country's export performance. Amable and Verspagen (1995) use panel data - from a sectoral as well as a country-wise perspective – to show that competitiveness in trade was significantly influenced by technological capabilities (once again based upon US patenting) in eleven out of the eighteen sectors, especially some high-tech industries such as drugs and medicines, instruments, computers and so on which have quite high values of the estimated coefficients. Importantly, most empirical studies use US patent data since there are institutional differences between countries which make it impossible to compare domestic patent counts. Moreover, the emergence in the twentieth century of the very strong position of the US as the major innovating country has led to a huge technological gap between the US and the rest of the world. As a result US patent data have been used for the patent proxies.

In addition, a number of applied papers have examined the product cycle concept. Aquino (1981) estimated comparative advantage under the orthodox version of the product cycle

[45] With the exception of the "natural resource intensive" industries such as food, clay and glass and so on, and a number of industries where patented innovations may be expected to be less of an appropriate proxy for innovativeness, such as textiles, ships and boat building and bicycles (Dosi *et al.*,1990).

model which emphasises the decline over time in the technology intensity of products as the main source of the changes in the pattern of international specialization in manufactures: new products are technology-intensive and technology-rich countries have a comparative advantage in their production; as products grow older their technology-intensity decreases and comparative advantage switches towards countries relatively well endowed with factors other than highly qualified labour. Thus Aquino employed some variables which contain country characteristics such as technology-endowment, physical-capital-endowments and home-market size for a selection of countries from 1962 to 1974. Meanwhile, measurement of technology-endowment in most countries was based on (a) past expenditures on R&D activities, (b) number of innovations per capita and (c) total wage cost per working hour, all related to manufacturing industries. Aquino found evidence that in most sectors the elasticity of trade to technology endowments falls over time (Aquino, 1981).

Audretsch (1987) investigated the hypothesis of whether industry attributes are assumed to be characteristic of each life-cycle stage, such as new products are R&D intensive, the skill level of the labour force, and the level of capital intensity, are in fact related to the various life-cycle stages. He divided sectors into three - growing, mature and declining sectors based on the long-term trend in sales volume, and then looked at the related inputs of R&D expenditure, skilled labour and capital intensity. He found that growing industries are associated with high R&D expenditure but are intensive in both skilled and unskilled labour, justifying perhaps an association between early stages of the product cycle and the role of tacit knowledge.

It is to be noted that empirical tests of the product cycle model are complex, not least because the barriers to creating indicators required to measure different levels of product standardisation for different products in different locations over time are formidable.

A large number of studies have been carried out to test technological change as a factor affecting international patterns of specialization. However, they may be based on different rationales which have not been absorbed into the mainstream of trade theory. As Gruber *et al.* (1967) addressed, “all roads lead to like between export performance and R&D”. It might however be useful to summarize as follows.

Whereas the traditional HO theory of trade ruled out the possibility of technology gap motivated trade by assuming common technology across countries, there is a growing literature which recognizes the increasing importance of technical change and considers differences in technological capacity as an important driving force for trade. This literature contains both the formulation of new theories of trade and the reformulation of traditional theories. The former group consists of the technology gap theory, the product life cycle theory and neo-Schumpeterian approach. Both technology gap and the product life cycle theories emphasize both process and product innovation as the prime causes of international trade. In other word both theories place technology at centre stage but some key features of technology - such as the dynamic implications from monopoly power and technological change - have been consistently neglected. However the neo-Schumpeterian approach emphasises an evolutionary view of technology, considering the dynamic implications of technology gaps on growth and specialization patterns. The reformulation of traditional theories, such as the neo-endowment theory of trade, extends the traditional two-factor model of trade to include a number of additional input factors, i.e., human capital and knowledge, while maintaining the assumption of a constant world production function. For instance, in a two-factor model, a country that has comparative abundance in knowledge endowments will have comparative advantage in producing knowledge intensive products.

3.4 Demand, Product Differentiation and Intra-Industry Trade

3.4.1 Trade between Similar Economies: The Role of Demand

Traditional comparative advantage models of trade are based upon differences in production possibilities between countries. These are evidently incapable by themselves of explaining trade between countries at rather similar stages of development, with similar endowments and consequently with similar levels of productivity. The concepts discussed in the last section based around innovation and diffusion help to explain such trade, but the demand side remains another possibility.

An early example of the role of demand was provided by the so-called 'Linder hypothesis' (Linder 1961). Linder drew attention to the role played by innovative entrepreneurship in meeting potential demands primarily for the home market where cultural and other ties are closer. The greatest export potential for such new products will be in markets where demand patterns are similar. If demand structures are primarily determined by per capita income, the hypothesis predicts a positive correlation between the latter and the intensity of intra-industry trade[46] (Bowen *et al.*, 1998). As Markusen *et al.* note however, while the hypothesis makes predictions about overall volumes of trade in manufactured products (Linder himself was content with the comparative advantage explanation of trade in primary products), it tells us little about the detailed pattern of trade which depends upon "the history of entrepreneurial activity in each market" (Markusen *et al* 1995, p. 203). Linder himself was Swedish, and clearly the model has great potential relevance in a European context where a large number of small economies with different cultures but with similar levels of development co-exist with each other.

The phenomenon of the simultaneous export and import of commodities classified in the same industry (intra-industry trade) between the similarly endowed industrial nations began to be acknowledged by many economists during the 1960s, although at the beginning some economists argued that it may be a purely statistical phenomenon[47] . However, even at the finest classifications there is still evidence of intra-industry trade (IIT). In addition, the traditional economic theory on the principle of comparative advantage had difficulties in explaining intra-industry trade; a number of researchers drew on empirical analysis for answers.

Empirical work on intra-industry trade can be dated to the pioneering work of Balassa (1966), with the most widely used measure of intra-industry trade provided by Grubel and Lloyd (1975). In particular, the latter work demonstrated the importance of intra-industry trade between developed countries with similar factor endowments and technological know-how. As noted by Greenaway and Milner (1983), as work on intra-industry trade continued, the interest of economists shifted from concerns with measurement towards coherent explanation. This observation reflected the many theoretical models that were developed from the late 1970s onward: e.g., by Dixit and Stiglitz (1977), Krugman (1979, 1980, 1982), Lancaster

[46] This is in contradiction to the prediction of the HO model that countries with different factor endowments will trade more with each other.

[47] Since they believed that intra – industry trade was as a result of an incorrect aggregation of goods into product groups called "industries" (Finger, 1975; Lipsey, 1976). The main argument was that by aggregating goods into industries, different definitions of goods' similarity are applied. Apart from the correct aggregation problem, others such as seasonal growing variations and mid-product processing refer to Markusen *et al.*, 1995.

(1979) and Dixit and Norman (1980). In general, models in this mould consider monopolistic power, economies of scale and product differentiation as joint determinants of trade flows, using various assumptions to demonstrate how intra-industry trade is generated in a world where firms produce differentiated products. These models essentially explain intra-industry trade in manufacturing products between countries with fairly similar preferences and income levels. The motivation of trade is found in both the production and the consumption sides, while in many the model is based upon Chamberlinian monopolistic competition[48] (Dixit and Stiglitz, 1977; Krugman, 1979, 1980, 1982). There are several important ideas behind the monopolistic competition model:

- Firstly, each firm is assumed to be able to differentiate its product from that of its rivals. Therefore each firm has a monopoly in its particular product within an industry and faces a downward sloping demand curve. In other words, not all of a firm's customers are tempted away by rival products because of a slight price difference.

- Secondly, product differentiation is of interest when firms produce under conditions of increasing returns to scale. This introduces a trade-off between the number of varieties and the cost of production for each variety.

- Thirdly, there are a sufficient number of firms for each firm to be assumed to take the price set by its rivals as given.

- Finally, freedom of entry into the industry establishes zero profits in the long-run.

In general, trade under monopolistic competition normally generates two powerful sources of welfare gain, from widening variety and increasing competition. First, the larger market created by the integration of economies allows for further product differentiation and the availability of a greater variety of products. In other words, there are gains from trade to consumers in all countries, and they arise from the increased variety of goods available. In

[48]In the 1930s, there were two important works - related to imperfect competition-monopolistic competition debate, which, derived independently, were published almost simultaneously in time, and which deeply influence the modern microeconomic theory, Robinson's Economics of Imperfect Competition (1933) and Chamberlin's Theory of Monopolistic Competition (1933). The latter in particular had a special view about market structure, considering a market structure as characterized by both competitive and monopoly elements, with the power of a producer to differentiate a product as part of competitive strategy. In addition, the market nature is characterized both by the number of firms and product differentiation, where firms control prices, quantities, and product quality (Silva, 2001).

addition, the existence of internal economies of scale may lead to a lower average price. Krugman (1979) introduces such a pro-competitive effect[49] from trade into the monopolistic competition model by assuming that the elasticity of demand falls as consumption rises, and requires that each individual firm's share of the market falls as trade opens up. To summarize, the welfare effect of free trade in the monopolistic competition model is that the price of the product falls and variety available to consumers increases.

A key element in applications of the monopolistic competition model to international trade is therefore a trade-off between price and variety where economies of scale are important. If these are 'internal' [50] in nature, then we need to abandon the assumption of perfect competition (Krugman and Obstfeld, 2003). In order to analyse this trade-off more precisely, new ways of modelling demand are required. Dixit and Stiglitz (1977) and Lancaster (1979) provided alternative demand modelling specifications. Dixit and Stiglitz (1977) contributed pioneering work to analyse the monopolistic competition which can be labelled as neo-Chamberlinian. In Dixit and Stiglitz's approach, individuals value variety while the production side of the economy is characterised by monopolistic rather than perfect competition. They employed a now widely adopted specification of the aggregate utility function:

$$u = U\left\{x_0, \left(\sum_i x_i^{\rho}\right)^{1/\rho}\right\} \tag{3.11}$$

where utility depends on consumption of the numeraire good x_0 and differentiated goods x_i which indexed from i to n. ρ measures the substitutability between varieties. Importantly, the Dixit and Stiglitz approach asserts that consumers do not have specific preferences for any variety and all varieties enter an individual's utility function in a symmetric way. This is sometimes therefore called the 'love of variety approach'. In an alternative approach, Lancaster (1979) asserts that consumers do have preferences for a specific or 'ideal' variety, and ranks all available varieties by their distance from this ideal. Compared with Dixit and Stiglitz, the essence of the Lancastrian approach is the contention that goods, rather than

[49] A classic presentation of the pro-competitive effect refers to Bhagwati (1965).
[50] Internal economies of scale arise because of the growth in the scale of production within a firm.

being direct objects of utility, are combinations of attributes, or characteristics. Lancaster contends that "individuals are interested in goods not for their own sake but because of the characteristics they possess, so that the demand for goods is derived and indirect, and depends on preferences with respect to characteristics and on the technical properties that determine how characteristics are embodied in different goods"(1979:17). This is therefore sometimes called the 'favourite variety' approach.

Importantly, both the 'love of variety' and 'favourite variety' approaches were explicitly incorporated into models of intra-industry trade in Krugman (1979) and Lancaster (1979), respectively. After these works, international trade literatures have provoked a large volume of research examining monopolistic competition and its resultant international trade patterns.

Some of the models developed in this period were not however based upon monopolistic competition, e.g., the well-known Brander-Krugman model considers oligopolistic market structures to demonstrate how intra-industry trade takes place even with homogeneous products (Brander and Krugman, 1983).

The study by Greenaway and Milner (1986) provides a comprehensive discussion of intra-industry trade, arguing that the most plausible explanation of the phenomenon is the existence of product differentiation. The concept of product differentiation can be adapted to distinguish intra-industry trade into further two categories, i.e., horizontal (the two-way trade of goods of similar quality which cannot be ranked according to quality) and vertical (trade of similar goods but of different quality, where quality commands a price premium). Unlike comparative advantage models, those based upon product differentiation recognise that competition between firms is rarely just about price, as price is just one attribute or characteristic of a product. Typically as products have become more complex, the role of these 'non-price' factors in explaining competitiveness has increased. These factors include not just characteristics 'intrinsic' to the product but more generally delivery and after-sales service aspects (Fagerberg, 1988; Greenhalgh, 1990; Hughes, 1986 and Pavitt and Soete, 1980). Quality features such as performance, design, reliability, variety and innovation have been widely recognised as being as important as price in determining the competitiveness of a country in international markets (Fagerberg, 1988; Greenhalgh, 1990; Greenhalgh *et al.,* 1994; Swann 1998; Temple, 1998 and Carlin *et al.*, 2001).

In order to distinguish 'vertical' from 'horizontal' differences in quality, unit values indices for quality analysis, which measure the average price of a bundle of items from a given product grouping, have sometimes been employed in order to evaluate international trade flows. For example, Temple (1998) conducted an analysis of unit values patterns of UK trade flows within the 12 major OECD economies in 1992. Unit value 'norms' were estimated for each commodity group on the basis of the geometric mean of the observed unit values across all countries. The value of the trade flows were then subdivided according to one of three categories - high-quality, medium-quality or low-quality. The line of separation was based (arbitrarily) on whether the logarithm of the recorded unit value exceeded the logarithm of the norm unit value by 0.2 or more (high-quality) or fell short of the norm by 0.2 or more (low-quality) in an attempt to separate 'vertical' differences from 'horizontal' differences in quality (see also Del Bono and Mayhew, 2001). While other studies have used patents and/or R&D as indicators of non-price competitiveness, standards have also been used as an important proxy for non-price factors in the determination of trade flows (Swann *et al.*, 1996; Temple and Urga, 1997), reflecting the analysis of chapter 2.

The discussion of chapter 2 indicates the potential importance of measurement technology for the economics of product differentiation, which it supports by providing measurement techniques and which make it easier for firms to differentiate their products on the basis of measurable characteristics. It is this link between measurement technology, product differentiation, and hence international trade, which will be investigated in the following chapters, both by theoretical and empirical models. The monopolistic model itself, which features product differentiation as a key element, therefore provides a natural framework for discussion of the links between measurement technology and trade.

3.4.2 Empirical Tests of Monopolistic Competition Models

The empirical relevance of monopolistic competition models has been considered in a number of ways. First and perhaps foremost have been attempts to test the predictions of the monopolistic competition models. Second have been attempts to introduce variables suggested by the models into empirical investigations of intra-industry trade more generally. The first approach is considered first.

The initial work which explained how the monopolistic model can generate testable propositions is the contribution of Helpman (1987), which led to further work including important papers by Hummels and Levinsohn (1995) and Debaere (2005). In his 1987 paper, Helpman developed a monopolistic competition model from which specific testable hypotheses were derived, providing some initial tests of these hypotheses. Similar to other monopolistic competition models of trade[51], scale economies and product differentiation are two other important reasons which induce specialisation. However, in Helpman (1987), there is a group of countries "A" where it is assumed that all countries are identical and each variety of a good is produced by a single country due to economies of scale. Moreover, the production processes of all goods are identical, therefore in the absence of trade barriers the prices of all varieties are the same - which can then be normalized to unity. Each country exports varieties of the differentiated product to one another, all consumers buy this variety; it is exported in identical quantities to all other countries. Then it follows that a good produced in any country is sent to all other countries in proportion to the purchasing country's GDP. In other words, the GDP of a country h is equal to the sum the value of production y^h_i of each variety i, as in (3.12)

$$Y^h = \sum_{i=1}^{N} y_i^h \tag{3.12}$$

where Y^h denotes total GDP in country h , y^h_i denotes country h's production of good i, since its price normalize to unity; y^h_i actually measures the value of production, and $i=1,\dots,N$ denotes products (any variety of a good counts as a distinct product). Therefore, the world GDP is the sum of GDPs of all countries h:

$$Y^w = \sum_{i=1}^{O} y^h \tag{3.13}$$

where w is abbreviation of the world, Y^w denotes the world GDP, and $h, f = 1,\dots, O$ denotes countries in the world.

[51] Such as Helpman and Krugman (1995).

A good produced in any one country is sent to all other countries in proportion to the purchasing country's GDP. Let s^f denote the share of country *f* in world GDP, as follow:

$$s^f = Y^f / Y^w . \tag{3.14}$$

where Y^f denotes total GDP in country *f*. Assume trade is balanced in each country, thus s^f not only denotes the percentage of country *f* in world GDP, but also evaluate country's *f* share of world GDP influences the intensity of bilateral trade between country *f* and country *h*. Moreover, as we measure each country's import as a portion of its GDP, then with balanced trade it is equal to its partner's export.

Let X^{hf}_i denote exports from country *h* to country *f* of product *i*. As mentioned earlier, all countries are assumed to be producing different products, and demand is identical, therefore the exports from country *h* to country *f* of product *i* are given by

$$X_i^{hf} = s^f \; y_i^h \tag{3.15}$$

Equation (3.15) implies that exports from country *h* to country *f* of product *i* is equal to the share of country *f* in world GDP multiplied by the country *h's* production of good *i*. In other words, exports to a country are determined by the size of the country, because there are no price differences and because all consumers have the same preferences. The only remaining differences are therefore different country sizes.

Total exports from country *h* to *f* over all products *i* (which is the same as total exports of country *f* to *h* because of the earlier assumptions) is,

$$X^{hf} = \sum_i X_i^{hf} = s^f \sum_i y_i^h = s^f Y^h = \frac{Y^f Y^h}{Y^w} = s^f s^h Y^w = X^{fh} \tag{3.16}$$

Summing the first term X^{hf} and last of these term X^{fh} of the equation (3.16), the bilateral trade between two countries *h* and *f* equals

$$X^{hf} + X^{fh} = \frac{Y^f Y^h}{Y^w} + \frac{Y^f Y^h}{Y^w} = (\frac{2}{Y^w}) Y^h Y^f \tag{3.17}$$

Equation (3.17) is an example of what is sometimes referred to as a 'gravity equation', where the bilateral exports from country h to country f are proportional to the product of their GDPs, which is denoted by Y^h and Y^f, as mentioned earlier.

The re-formulation of equation (3.17) with the equation (3.16), obtained

$$X^{hf} + X^{fh} = 2s^h s^f Y^w \tag{3.18}$$

Equation (3.18) is an important characteristic of Helpman's model (1987). Clearly as can be seen from equation (3.18), it emphasises the role of different country size. A variable representing size of a country is its share in the world's GDP. Different values of these shares by trading partners express the differences in their shares.

In order to further investigate the role of the member countries in an economic region and evaluate the economic position of a region in the global economy, it is assumed that there are two countries (h,f) constituting region A. GDP of region A (Y^A) is therefore equal to

$$Y^A = Y^h + Y^f \tag{3.19}$$

where Y^h denotes GDP of country h, Y^f denotes GDP of country f within the region A. s^{hA} denotes the share of country f in region A's GDP, s^{fA} denotes the share of country h in region A's GDP. The relative shares of GDPs of every country in the regional GDP are, respectively,

$$s^{hA} = Y^f / Y^A \tag{3.20 a}$$

$$s^{fA} = Y^h / Y^A \tag{3.20 b}$$

And the GDP of regional A relative to the world GDP is,

$$s^A = Y^A / Y^w \tag{3.20 c}$$

Then equation (3.18) can be rewritten as

$$(X^{hf} + X^{fh}) / Y^A = 2s^{hA} s^{fA} s^A \tag{3.21}$$

Equation (3.21) implies that the volume of trade among countries in region A relative to their GDP depends on the position of every member country in the region and on the relative importance of the region's GDP in the world. Since assuming that region A contains only two countries (*h*,*f*), thus $(s^{hA}+s^{fA})=1$. On squaring the right hand side and left hand side at the same time, the following result is obtained:

$$2s^{hA}s^{fA}=1-(s^{hA})^2-(s^{fA})^2=1-[(s^{hA})^2+(s^{fA})^2] \quad (3.22)$$

Equation (3.22) presents a simple version of Helpman's theorem (1987) under the assumptions which have been mentioned before. The volume of trade relative to GDP is proportional to the dispersion index defined for the region A as,

$$disp=1-\sum_{i\in A}(s^{hA})^2 \quad (3.23)$$

Then bringing equation (3.23) into equation (3.21), the volume of trade among countries in region A (VT^A) relative to their GDP (Y^A) is,

$$\frac{VT^A}{Y^A}=s^A(1-\sum_{i\in A}(s^{hA})^2) \quad (3.24)$$

where *N* indicates the number of countries in the region A. The term in brackets in equation (3.24) provides a measure of the dispersion of size, as shown in equation (3.23). Clearly, since assuming the shares of regional GDP sum to 1, it is maximized for countries of the same relative size. Importantly, equation (3.24) shows that volume of trade in the region is related to the relative size of countries constituting the analyzed region. It is expected that with increasing similarity of trading partners their bilateral trade will intensify.

For the empirical analysis, Helpman used data from 14 OECD countries for the years 1970 to 1981 to test the prediction of the model. He calculates the total bilateral trade among them as a portion of their joint GDP and relates it to their size similarity while assuming that the share of the OECD countries in the world economy, volume of trade in group of A, stays constant.

He plots both series and finds a positive relation: more similarity in terms of country size is translated into higher trade to GDP ratios.

The results provided by Helpman triggered several other studies - noteworthy are Hummels and Levinsohn (1995) and Debaere (2005). Hummels and Levinsohn (1995) based their study on Helpman's (1987) model and extended the empirical work to include non-OECD countries as well. They treated each OECD country pair in each year as an observation and then generated all country pairs for Helpman's 14 countries for the period 1962 to 1977, which allowed them to apply panel data techniques[52]. Hummels and Levinsohn also randomly chose 14 non-OECD countries for which intra-industry trade is not important and constructed a similar panel. However the empirical support for Helpman's theory was inconclusive. For the OECD countries, results supported Helpman's original findings. For non-OECD countries, there was little empirical evidence of intra-industry trade. Hummels and Levinsohn (1995) interpreted the latter results as evidence that the fit of the simple gravity equation may be due to something other than trade in differentiated goods.

Debaere (2005) employed the aggregate dataset compiled by Feenstra *et al.* (1997) to investigate the validity of the Helpman prediction. The data contains bilateral trade flows for 14 OECD and 14 non-OECD countries. In particular, there are about 7% zero bilateral trade observations in the group of non-OECD countries, Debaere taking the logarithmic approach to resolve it. In addition, the Tobit regression and linear fixed effect regression methodologies have been employed.

Debaere's work specified a group of countries A as any pair of countries, A= $\{h,f\}$, and then proposed a more complete treatment and transformed Helpman's equation (3.17). He employed the linear form of the equation (3.24) obtained earlier:

$$\ln(\frac{X^{hf}+X^{fh}}{Y^h+Y^f}) = \ln(s^h+s^f)+\ln[1-(\frac{Y^h}{Y^h+Y^f})^2-(\frac{Y^f}{Y^h+Y^f})^2] \qquad (3.25)$$

[52] This is an important innovation since bilateral trade flows are known to systematically depend on country-pair specific factors such as bilateral distance, tariffs, a common border, common language, etc. These non-random factors can be accounted for in a straightforward way by country-pair fixed effects in a panel (Debaere, 2005).

As before, X^{hf} is exports from country h to country f, X^{fh} is exports from country f to country h, Y^{h} is income in country h, Y^{f} is income in country f. s^{f} is country h's share in world GDP, s^{h} is country f's share in world GDP as well. The first term on the right hand side of equation (3.25) indicates that intra-industry trade is larger among relatively large countries; the second term of equation (3.25) shows the extent to which countries are similar in size.

Debaere analyses these relations employing a dataset from 1970 to 1989, over a sample of OECD and non-OECD countries. Recognizing that the variables also depend on time, therefore rewriting the estimating equation in (3.25) as

$$\ln\left(\frac{X_t^{hf} + X_t^{fh}}{Y_t^h + Y_t^f}\right) = \alpha_{hf} + \gamma \ln(s_t^h + s_t^f) + \beta \ln(Dispersion_t^{hf})$$
$$dispersion^{hf} \equiv 1 - [Y^h/(Y^h + Y^f)]^2 - [Y^f/(Y^h + Y^f)]^2 \qquad (3.26)$$

where α_{hf} is a fixed effect for each country pair, γ is a coefficient on the log sum of country shares, and β is a coefficient on the size dispersion index. By using different econometric techniques and different measures of GDP, Debaere found that for 14 OECD countries, increased trade to GDP ratios are positively related to their shares in world trade and to a similarity in size index. However, for the group of non-OECD countries, Debaere found that the index of similarity does not play a significant role in trade with non-OECD countries.

In addition to the approach suggested by Helpman, there is a considerable amount of econometric studies that have been carried out aimed at analyzing the determinants of IIT during last few decades. These can shed light on the relative importance of variables suggested by the monopolistic model compared to other explanations of intra-industry trade. As suggested by Balassa and Bauwens (1987), the determinants of IIT can usefully be split into country and industry characteristics[53]. Many of the empirical studies have been focused either on country or industry characteristics independently, or both together, and these will be

[53] The country characteristics include common (average per capita income, distance, income differences, average country size, size differences, common borders and average trade orientation) and specific (participation in economic integration schemes and languages) country characteristics. Industry characteristics include product differentiation, marketing costs, variability of profit rates, economies of scale, industrial concentration, foreign investment, foreign affiliates, and tariff dispersion and so on.

discussed further in Chapter 5. Below are brief reviews of three important works, which may be taken as illustrative of the general approach.

Bergstrand (1990) estimated the role of country specific variables such as the average levels of and inequalities between their GDPs per capita using data for fourteen countries for 1975. A unique aspect of this empirical study is the inclusion of capital-labour endowment ratios and their corresponding inequalities. Formal theoretical models of intra-industry trade such as that provided by Helpman (1981) and Helpman and Krugman (1985) stressed the negative correlation by interpreting per capita income differences as capital-labour endowment ratio differences. Moreover, Helpman and Krugman (1985) suggested that higher average per capita income represents a higher average capital-labour endowment ratio. Bergstrand (1990) argued that if the differentiated good industry is capital-intensive then the share of intra-industry trade will be greater than the average capital-labour endowment ratio of the two countries. Bergstrand (1990) provided eight propositions on the determinants of IIT, that is, the share of IIT between countries *h* and *f* will be:

- Lower, the greater the inequality between their capital-labour endowment ratios (Inequality of capital-labour endowment ratio);
- Lower, the greater the inequality between per capita incomes because of a greater divergence in tastes (Inequality of per capita GDPs);
- Higher, the greater the average capital-labour endowment ratio of the two counties, depending upon relative factor intensities in production (Average capital-labour endowment ratio) ;
- Higher (lower) in the luxury (necessity) good, the higher the average level of economic development (Average per capita GDP);
- Lower, the greater the inequality between their economic sizes (Inequality of GDPs);
- Higher, the greater their average economic size (Average GDP);
- Lower, the greater the inequality between their tariff levels (Inequality of tariff levels);
- Lower, the greater their average tariff level (Average tariff level).

Within Bergstrand's (1990) work, two regressions are reported to determine cross-country bilateral intra-industry trade, one including all variables, the other excluding the two capital-labour ratio variables. The regressions are estimated using ordinary least squares analysis. For the results of estimation excluding the capital labour endowment ratio, all the variables had the expected sign on their parameters, with significance, except average GDP per capita which is negative and significant. For the empirical result including the capital labour endowment ratio, the coefficient estimate for the inequality of capital-labour endowment ratio is negative, but statistically insignificant at conventional levels. The coefficient of average capital-labour endowment ratio is negative and significant at the 1% level which suggests that these manufactured products are labour intensive in production. In short, the empirical results support these propositions.

Hughes (1993) was one of the first to consider the time dimension as one of the main industries' characteristics to determine the intra-industry trade across the largest OECD economies in the 1980s[54]. She uses panel data pooling time series (1980-7) and cross-section data (68 four-digit industries) for six countries (US, Japan, Germany, France, UK and Italy). Hughes focuses on three groups of industrial characteristics, namely heterogeneity, product differentiation and economies of scale, including factors that may cause to and so would impede inter-industry trade. Heterogeneity is measured by the number of UK SIC classes corresponding to each ISIC class. To measure the product differentiation, three variables were considered: R&D expenditure as a proportion of values added from 1980 to 1987, professional and technical staff as a proportion of total employment for the same period and the operative staff as a proportion of total employment. The final factor is economies of scale; here as with other parts of the literature, two measures of scale are used, one is average plant size in net output terms of the largest 50% of the distribution as a proportion of total net output 1980-7, another one is the five firm concentration ratio which is commonly used to measure economies of scale in other empirical studies, although it is sometimes also used as a measure of market power. The results of this study vary from country to country, but in general, all results support previous studies that have found a role for heterogeneity, product differentiation and economies of scale. The results suggested that the structure of the labour force might be an explanatory variable in affecting intra-industry trade. In particular, professional and technical staff may, on the one hand, promote product differentiation and so intra-industry trade and, on the other, may proxy for human capital and so impede intra-industry trade. This suggests indeed that the interaction of country- and industry-specific characteristics is important and that the precise nature of industry effects varies from country

[54] Therefore still include the work by Hughes (1993) into industry characteristics studies groups.

to country (Hughes, 1993).

Balassa and Bauwens' (1988) contribution attempts to explain the intra-European trade in manufactured goods. They have considered the impact on bilateral trade in individual industries of factors affecting inter-industry specialization and intra-industry specialization, as well as the two together. Their country characteristics included GNP per head and country size as measured by GNP, as well as distance and common borders. The industry characteristics included economies of scale, industrial concentration, and the Hufbauer index as product differentiation. The results suggested that trade between any two countries is positively correlated with their average per capita income and country size, and negatively correlated with inter-country differences in these variables, particularly showing that product differentiation tends to increase intra-industry trade.

In summary, a common approach in most empirical literatures is to compare the coefficient signs of regression models with hypotheses suggested by the various trade models. However, there are generally no strong theoretical grounds for the relationships of many determinants of IIT discussed above. As Leamer and Levinsohn (1995) have argued, although these studies produce interesting results, generally in broad support of the a priori expectation, there are also some important problems. First, it is often not clear which variables to include and to exclude which raises the possibility the study will be reduced to a "data-mining" exercise until some plausible specification has been found. Second, it is often difficult to find proxies for variables that are important in theory. For example, economies of scale, due to the data not being available, it may be tempting to use industry concentration indices to gain some indication as to whether or not imperfect competition prevails. Accordingly, measurement issues of the explanatory variables of intra-industry trade model will be discussed further in chapter 5.

This section has discussed several models based on monopolistic competition that can help to explain intra-industry trade. The treatment of technology in the monopolistic competition models is as a factor adding to product differentiation and thus the technology intensity of products can be used as a proxy for their heterogeneity. However, these models have neglected the essential endogenous feature of technology which raises another new issue – the dynamic theory of comparative advantage. The dynamic theory of comparative advantage considers technology to be endogenous and a strategic tool which can be manipulated to gain a trade advantage. This will be discussed in the next section.

3.5 Dynamic Comparative Advantage

3.5.1 The Concept of Dynamic Comparative Advantage

Although the theory of comparative advantage has been acknowledged by many economists as the most important concept in international trade theory, there are clearly limitations to the static comparative advantage concept underlying the Ricardian and the HO models. Romer (1986) generated a theoretical model based upon endogenous technological progress which has become a major concern of macroeconomic theories. Inspired by Romer and his followers, trade economists brought technological change and growth into a more central place in international trade theory, where specialization patterns become a determinant of growth, rather than the other way around. As Wakelin (1997) has argued, the view of technology as a strategic tool which can be manipulated to gain a trade advantage was in fact the precursor to a dynamic theory of comparative advantage considering technology as endogenous. Moreover, the development of new techniques has led to the treatment of innovation as an endogenous factor as applied to trade theory, leading to models in which comparative advantage itself is endogenous and can be created over time, and in which the export specialisation of a country can affect its growth rate. Taking this view can impact upon the welfare implications of comparative advantage.

Among the work considering the concept of dynamic comparative advantage, there are three notable theoretical works which develop the concept of dynamic comparative advantage and which give a key role to either learning by doing or to investments in innovation and knowledge enhancing activities, particularly R&D, each of which may alter a country's comparative advantage over time.

The model by Krugman (1987), examines the impact on specialisation of 'learning by doing,' in a world with two countries, Home and Foreign. The model is developed with only a single factor, and the pattern of specialization depends upon relative labour productivities which, together with relative wages, determine the share of industries in which Home (or Foreign) has a comparative advantage. Labour productivity in turn depends upon the degree of knowledge gleaned through learning by doing, i.e., through experience gained from cumulated production. The functional form here is the well known learning curve.

Knowledge however 'spills over' between each economy and this diminishes the potential impact of a steep learning curve. However the model provides possible justification for a policy of 'infant industry' protection. A prohibitive tariff allows an economy to gain experience in the industries protected. The tariff may be removed when the industry becomes competitive. Such a policy is most likely to be effective where the relative wage is initially low and the labour supply is large (so that cumulated production is also large). Krugman notes the relevance of the model for the development of Japanese industrial policy in the early post-war period.

Whether the type of protection discussed by Krugman may be welfare enhancing is examined by Redding (1999) who builds upon Krugman's approach, examining a model describing the relationship between endogenous comparative advantage, economic growth and economic welfare. Importantly dynamic comparative advantage is defined in terms of *the rates of growth* of opportunity costs or production over time which are influenced by comparative rates of learning by doing. As mentioned, in his formal model, there are two economies, i.e., home and foreign; each country produces two goods: a low-technology good and a high-technology one, distinguished by different rates of learning by doing. Labour is the only factor of production. He argues that trade and specialisation according to comparative advantage will lead to reallocations of resources between the 'low-tech' and 'high-tech' sectors. These reallocations of resources affect rates of learning by doing and productivity growth in each sector of the two economies. The new allocation in turn determines relative rates of productivity growth, and thereby feeds back to shape the evolution of productivity levels over time, and determining a pattern of endogenous comparative advantage. His model shows that specialization according to current comparative advantage under free trade may be welfare reducing, and that selective intervention may be welfare improving both for the economy undertaking it and for its trade partner. Redding opens his article by reporting on the successful example of Korea's steel industry. In the 1960s the World Bank regarded the potential for an integrated steel mill as being "a premature proposition without economic feasibility" (cited in Redding 1999, p.15). Beginning production in the 1970s with various types of government support, Pohang Iron and Steel became one of the lowest cost steel producers in the world by the mid 1980s.

In order to fill some largely neglected gaps in understanding the effects of trade structure on rates of growth, Grossman and Helpman (1990) constructed a dynamic trade and growth model driven by endogenous technological progress. This model allows for comparative advantage which is defined by cross country differences in efficiency at R&D against productivity in manufacturing, which bears importantly on the growth effects of economic structure and commercial policies. The model assumes that the world contains two countries, each with three productive activities: the production of the final manufactured good, the production of a continuum of varieties of differentiated intermediate products, and research and development. There is a single non-produced 'primary factor' in the model, namely labour. The productivity of this factor in the three activities varies internationally giving rise to comparative advantage. The key idea is the variety of intermediate inputs available – the greater the variety, the greater the efficiency of R&D (since this variety represents cumulated knowledge), as well as the greater the efficiency of manufacturing. The main conclusion of their model is that comparative advantage can be obtained through experience in research which raises relative productivity at R&D: the higher long run growth rate, the larger effective labour force of the country with comparative advantage in R&D. In other words, the country's investment in R&D will raise its dynamic comparative advantage; in addition to specialisation in the R&D sector a country can achieve a higher growth rate. However these effects depend critically on two empirical issues – whether intermediate inputs are internationally tradable, and whether knowledge spills-over across economies.

3.5.2 Empirical Tests of Dynamic Comparative Advantage Models

Endogenous growth models have raised a number of hypotheses regarding growth, including the impact of country size and variety on growth. As far as the generation of dynamic comparative advantage is concerned, the question of spillovers is fundamental. The innovative activities of firms not only lead to new products whose benefits the firms can appropriate, but also contribute to a general stock of knowledge upon which subsequent innovators can build. Over time, the foundation of general knowledge grows, allowing more differentiated products to be introduced without a continual increase in the research resources that must be extended. This is referred to as a 'knowledge spillover', so-called because the benefit of innovation accrues not only to the innovator, but "spills over" to other firms by raising the level of knowledge upon which new innovations can be based (Branstetter, 2001) Thus, knowledge spillovers serve as the "engine of endogenous economic growth" (Grossman and Helpman, 1995). As made clear from the discussion in the last section however, the relevance of endogenous growth models for the creation of dynamic comparative advantage depends critically upon whether knowledge spills-over between economies. The last decade has seen several studies which seek to detect such spillovers.

Coe and Helpman (1995) employed data for 21 OECD countries plus Israel during the period 1971-90 to test for international spillover effects. They state that the benefits from a country's own R&D is that R&D produces goods and services that can bring more effective use of existing resources and thereby raise a country's productivity level. The benefits from foreign R&D not only consist of learning about new technologies and materials, production processes, or organizational methods, but also emanate from imports of goods and services that have developed by trade partners. Thus they assumed that if international spillovers occur, the growth rates of countries should be correlated not only with their own 'knowledge stocks' but also those created by the R&D expenditures of their trading partners. Cumulated R&D expenditures – subject to depreciation - are used as a proxy for these stocks of knowledge. For the construction of foreign R&D capital stocks they use import weighted sums of a trade partner's cumulative R&D spending. The evidence they found is that total factor productivity (TFP) growth rates at the country level are indeed correlated with own- and partner-country R&D expenditures, lending support to the idea that R&D carried out in one country spills over to its trading partners.

However, in the time series estimation of each country in Coe and Helpman (1995)'s work, of the relationship between the TFP growth rates and R&D expenditures, the Dickey-Fuller and the augmented Dickey-Fuller tests generally do not reject the presence of a unit root. In other words, regressions of TFP on R&D could be leading to estimates that are significantly different from zero using conventional t-tests, even though the relationship might be spurious. Therefore, Keller (1998) used the same dataset of Coe and Helpman (1995) but reconstructed the weighted R&D expenditures of trading partners using random import weights. This yielded the result that significant international spillovers were still estimated from foreign R&D stocks constructed using randomly assigned weight. This casts some doubt on the claim that patterns of international trade are important in driving R&D spillovers. However, the work by Funk (2001), who used panel co-integration techniques to correct the unit-root problem, examined the relationship between trade patterns and international R&D spillovers, and found a significant relationship between TFP and export-weighted R&D expenditures of partner countries, supporting the idea that exports receive substantial research spillovers from their customers.

Further work by Keller (2002), continuing to investigate international spillovers, used manufacturing industries' data for fourteen OECD countries for 1970 to 1995. He again constructed a weighted average of R&D expenditures in other countries, but used the geographic distance between each partner as the weight. He denoted D_{cg} is the bilateral geographic distance between country c - the technology recipient country - and country g - the technology sender. He weighted the other countries' R&D expenditures by $e^{-\delta D_{cg}}$ .The parameter δ captures the degree of localization of R&D, in other words, it measures the speed of the impact of other countries' R&D expenditures on TFP which diminishes exponentially with distance. If δ turned out to be positive and highly significant, it would indicate the spillovers are quite highly localized. The empirical results suggested that there is evidence for spillovers across borders but that these are quite localised. This result provides some evidence of the importance of tacit knowledge in technology.

Patent data has also been used to measure international spillovers. Branstetter (2001) conducted a study which investigated the impact of international knowledge spillovers on innovation and productivity at the firm level, based on the panel data from United States and Japan. The intention was to measure the impact of the R&D of foreign firms on each domestic firm's patenting activity. Here the R&D stocks were used to indicate potential spillovers, and the weights have been constructed on the basis of a 'technological distance' matrix (i.e., constructed on the basis of the degree of similarity in the patenting of the foreign firm to the domestic firm). The results do not provide strong evidence for international spillovers compared to those from domestic firms, similar to Keller (2002) above.

3.6 Conclusion: Questions and Hypotheses

The discussion of this chapter has highlighted the role played by technology in determining trade flows. All the various models of trade theory are shown to be relevant to the interpretation of trade flows seen in the world economy today, even if they are sometimes difficult to discriminate in empirical tests. Once technological differences are allowed for even the HO model has been shown to make useful predictions. That countries differ in both their access to technology raises of course the question of how technology differences emerge and why they may persist, further raising the question of technology spillovers. Here, while empirical evidence does point to important technology spillover effects, the mechanisms involved are less obvious. However at several points, the role of tacit knowledge appears to provide some useful insight, not only in interpreting the theory (e.g., product cycles or imitation lags) but also in understanding why differences in technology may persist over time. In addition, this chapter has touched upon the literature, including the monopolistic competition model of trade and endogenous growth models which feature the generation of varieties of goods as an important element. Here, there is clear relevance for the current thesis, since the development of measurement technology is directly relevant to both the generation of variety and through, for example the use of codified knowledge in the form of standards, to technology spillovers. Examination of these relationships provides the most important objective for the remainder of this thesis.

As discussed in chapter 2, there are several important mechanisms through which development in measurement technology impacts upon trade flows. Apart from these mechanisms, a strong measurement infrastructure also plays a critical role in supporting development of new measurement techniques, procedures and equipment, and the updating of measurement technology which may assist national firms in obtaining a comparative advantage in earlier stages of the product cycle. Differences in infrastructure across economies may lead to or relate to technology gaps and therefore have a great influence on international trade. Antonelli and Patrucco (2001) suggest that if institutional and technological differences between national innovation systems occur, the structure of cost, learning capacity and scientific and technological knowledge can lead to idiosyncratic and path dependent behaviour. On the other hand, in the EU context, the development of a common measurement infrastructure may be seen as part of the creation of a single market. Here, as we saw in chapter 2, the public good effects of the output produced by measurement infrastructures often takes place through the channel of standardisation, and formal standards provide a key mechanism for delivery of the benefits of a developing measurement infrastructure.

According to what has been reviewed and discussed, this thesis will address two important issues for examination in later chapters:

- Does a strong measurement infrastructure promote product variety and intra-industry trade?
- Do all countries in the EU have equal access to measurement infrastructure? Or is it a source of comparative advantage?

International trading patterns in the EU provide an important means for examining these questions in more detail. Rather similar development levels (especially prior to enlargement) mean that the Heckscher-Ohlin model of trade, or those based upon very different demand patterns, may be less relevant. On the other hand, despite similar endowments and similar levels of income, access to measurement infrastructure in the European countries may be very different. Moreover, along with the large amount of intra-industry trade between these industrial countries, measurement standards like other proxies such as R&D expenditure or patents can be viewed as a special resource endowment representing technological innovation, implying a comparative advantage in trade performance in areas where the infrastructure is important. At the firm level, measurement technology not only helps improve product quality but also determines the ability of firms to differentiate their products. Since there is clearly a close relationship between product differentiation and innovation which is supported by measurement technology, the latter should serve to increase intra-industry trade.

In linking measurement to trade, the current study is related to a small body of literature linking standards (and hence codified knowledge) to trade. The pioneering paper by Swann *et al.* (1996) integrated for the first time technical standards (in general rather than measurement related standards) as a technology indicator in the estimation of UK trade flows. This paper studied the effects of standards setting activity on trade performance and examined the relationship between a measure of British trade performance in 83 manufacturing sectors and the number of British standards and German standards in these sectors together with a set of other economic variables. The data were employed at the 3-digit Standard Industrial Classification (SIC) level for the period 1985-1991. This study found that standards are trade creating (increasing both imports and exports) but there was also some evidence that they increase competitive advantage (i.e., some positive effect on net-exports).

A number of similar studies have provided further evidence in this area. Temple and Urga (1997) compare the effects of standards with those of other non-price factors in trade performance. Their results confirm the findings of Swann *et al.* (1996) regarding the importance of institutional standards for trade and that German standards also promote non-price competitiveness. In addition, Blind and Jungmittag (2000) test the impact of national and international standards on German world trade and the bilateral German–UK trade flows, the results showing that standards broadly had a trade creating effect. Blind (2001) found that his intra-industry trade model supports the view of the general trade fostering effect during the study of standards and bilateral trade between Germany, Austria and Switzerland. Recent research by Moenius (2004) examined the view that country specific product and process standards are barriers to trade and that harmonizing standards promotes international trade. The econometric analysis generally confirms that bilaterally shared standards are favourable to trade. However, in general, the number of country specific standards of importers is a barrier to trade. While country specific standards of importers reduce imports for non-manufactured goods, they do promote trade in the manufacturing sector.

The underlying hypothesis is therefore that the measurement infrastructure has an impact upon intra-industry trade, because it underpins the ability of firms to generate variety. In the subsequent chapters this hypothesis is examined both theoretically and empirically. The role of variety is central to the monopolistic competition model of trade, and it seems natural to extend this to a consideration of the impact of measurement infrastructure on trade. This is the aim of the next chapter.

Chapter 4

A Model of Measurement and International Trade under Monopolistic Competition

4.1 Introduction

The previous chapter considered the literature relating technology to trade, reviewing a number of approaches that were relevant to a consideration of the specific role played by measurement. Among the theories examined, the model of monopolistic competition – which explicitly considers the process of product differentiation – appeared to be particularly relevant. The purpose of the present chapter is to develop this model to make the link between measurement and trade more explicit. In the model, the concept of measurement infrastructure is used to describe a public good type input into the costs of individual firms. Although the focus on this chapter is on the generation of variety and intra-industry trade on the basis of measurement infrastructure, a strong measurement infrastructure can also be viewed as a special resource endowment creating the potential for comparative advantage in trade. The model builds on the work of Krugman (1979) and Lawrence and Spiller (1983). Krugman's work (1979) has been regarded as a landmark contribution to the evolution of international trade theory. It was the first theoretical study which explains intra-industry trade under the model of monopolistic competition with increasing returns. Lawrence and Spiller's model is the multi-sector extension of Krugman's (1979) work which analyses the comparative advantage issue. Before considering these contributions in more detail, it is helpful to locate these models in the wider context of trade theory.

As shown in Chapter 3 there are plenty of models which consider the determinants of international trade, both of an inter-industry or intra-industry kind, using assumptions of competitive or imperfectly competitive market. A typology of different types of model can be illustrated in the form of a tree as in Figure 4.1; the tree-diagram is based on Fontagne and Freudenberg (2002).

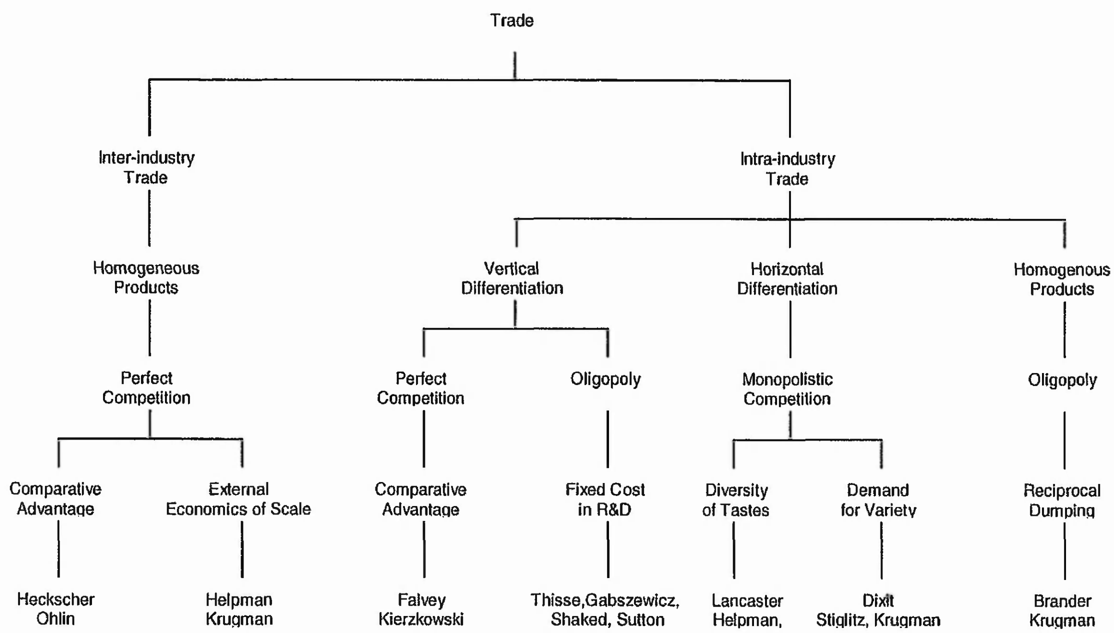

Figure 4.1 Market Structure, Differentiation of Products and the Determinants of Trade

(Sources: Fontagne and Freudenberg, 2002)

Trade can in general be divided into two categories, namely *inter-industry trade* and *intra-industry trade* (IIT). Inter-industry trade is defined as trade between countries that involves the exchange of products that belong to different industries. For example, one country exports footwear to another country in exchange for steel. Intra-industry trade is defined as trade between countries which involves the exchange of products that belong to the same industry. For instance, Germany exports Volkswagens to Italy and Italy exports Fiats to Germany. In addition, as Figure 4.1 shows, analysis of inter-industry trade has often been on the basis of comparative advantage and the assumption of homogeneous products under perfect competition. This case was addressed by Heckscher and Ohlin and became prevalent in the literature from the 1940s. With the emergence of the observation of increasing intra-industry trade between developed countries by many trade economists in the 1960s, less attention was paid to traditional trade theory. However, an important contribution to the comparative advantage literature was made by Helpman and Krugman (1985) who built an important link between external economics of scale and intra-industry trade.

In contrast, intra-industry trade can be divided into three categories as in Figure 4.1. The first two, i.e., *vertical differentiation* and *horizontal differentiation*, are related to markets with product differentiation, while the third one is for *homogeneous products* produced in oligopolistic markets. The main characteristic of the latter model (also called 'reciprocal dumping') was originally developed by Brander and Krugman (1983). The distinction between the former two categories is based upon vertical and horizontal product differentiation. Vertical differentiation refers to products belonging to the same industry but which differ in quality, such that consumers could agree on the order in which products may be ranked. This allows – at least in the absence of information asymmetries – for superior products to command a price premium. Moreover, product with vertical differentiation can be produced under two different markets, namely perfect competition or oligopolistic markets. The former has been analysed within a comparative advantage framework by Falvey and Kierzkowski (1987); later models have stressed the fixed cost in R&D leading to product differentiation – e.g., Gabszewicz and Thisse (1979) and Shaked and Sutton (1982). Horizontal differentiation refers to a situation where the products belonging to an industry possess the same attributes, but these are mixed in different ways, giving rise to differences in style, appearance and marginal performance capabilities between one product and another.

In this thesis we focus on horizontal product differentiation under monopolistic competition. Demand conditions can be divided into two types - *diversity of tastes* and *demand for variety*. The diversity of tastes approach is based on the neo-Hotelling model (Hotelling, 1929) which was significantly developed by Lancaster (1975, 1979). Lancaster presented a model in which consumers differed in their 'ideal variety' of a differentiated good. Lancaster (1980) as well as Helpman (1981) applied the 'ideal variety' approach to international trade under the H-O framework. An alternative approach is neo-Chamberlinian monopolistic competition; this model dates back to Chamberlin (1933) and Robinson (1933) who presented graphical analyses, and Dixit and Stiglitz (1977) who provided a mathematical formulation. Compared with Lancaster's 'ideal variety', Spence (1976), Dixit and Stiglitz had a single representative consumer gaining utility by demanding varieties of the differentiated good, in what is called the 'love of variety' approach. Krugman (1979, 1980, and 1981) applied the 'love of variety' approach to build a standard model, which successfully explained international trade under monopolistic and establishing the influential 'New Trade Theory' discussed in Chapter 3. The approach adopted here follows the Dixit and Stiglitz 'love of variety' approach.

The plan of the chapter is as follows. Section 4.2 describes the monopolistic competition model of Krugman (1979), and then briefly introduces the Lawrence and Spiller (1983) model. Section 4.3 presents the model of this thesis. Section 4.4 draws a conclusion.

4.2 The Krugman Model

In this section we review two models which are fundamental to the development of the theoretical model in this thesis, those of Krugman (1979) and Lawrence and Spiller (1983). The former model demonstrates how, with decreasing costs in production and (horizontal) product differentiation, intra-industry trade may be created even between two identical economies. Lawrence and Spiller's later model was inspired by Krugman (1979) and considerably extended it: not only by including two sectors (a differentiated products sector which is relatively capital-intensive; and a homogenous products sector which is relatively labour-intensive), but also by assuming that there are initial capital expenditures for a firm before entering the market. This is critical to the approach developed here. However, the welfare gains from both models stem from the increase in the number of product varieties.

4.2.1 Setup of the Krugman Model

Consider an economy with a single factor of production, labour. The economy produces a differentiated good with a large number of varieties. Each variety, indexed by i, is produced by a single firm. We order the products so that those actually produced range from 1 to n. There is symmetry in both production and consumption. This means that each variety has the same weight in the consumer's utility function and is produced using the same production function. The utility function of a representative consumer is written as:

$$U = \sum_{i=1}^{n} v(c_i) \ , \quad v' > 0, v'' < 0, \tag{4.1}$$

Where c_i is the individual's consumption of variety n. The utility function assumes diminishing utility to increases in the consumption of a given variety, and with more varieties consumed, holding total consumption constant, total welfare increases. In addition, Krugman's (1979) approach is based on the assumptions that there are a large number of firms, each one producing a single variety, indicating product differentiation, there is freedom of entry and exit (implying zero profits in the long run) and all varieties enter the consumer's utility function symmetrically.

Labour is the only factor of production and all goods have the same cost function, given by:

$$l_i = \alpha + \beta x_{i,} \alpha, \beta > 0 \tag{4.2}$$

Where l_i is labour used in producing good i. α is a assumed fixed cost, β representing marginal cost and x_i is the output of good i. This equation implies that there are scale economies, with average cost great than marginal cost.

In autarky, the production of good i must equal the sum of individual consumptions of that good:

$$Lc_i = x_i \tag{4. 3}$$

L is total labour force (which is exogenously given), c_i is the individual's consumption of good i, thus Lc_i is the total demand in the market of good i, and x_i is the total supply of good i.

The full-employment condition can be written as:

$$L = \sum_{i=1}^{n} l_i = \sum_{i=1}^{n} (\alpha + \beta x_i) \tag{4.4}$$

Given the symmetry of the model, all goods will be produced in the same quantities at the same price:

$$p = p_i ; l = l_i ; x = x_i \tag{4.5}$$

where p denotes the price.

4.2.2 Profit Maximising Equilibrium of a Monopolistically Competitive Firm

The monopolistically competitive firm faces a downward-sloping demand curve, which indicates the price is a function of output, $p_i(x_i)$. Moreover, the firm simply produces the quantity that maximizes economic profit. This occurs at the intersection of the marginal revenue and marginal cost curves. Therefore, the marginal revenue will be equal to marginal cost and also will equal to $p_i(1-\frac{1}{\varepsilon})$, where ε is the absolute value of price elasticity of demand. This result is different from perfect competition market structures. In the competition case, the firm faces a flat demand curve – an infinitely elastic demand curve. This means that $\frac{1}{|\varepsilon|} = \frac{1}{\infty} = 0$. Thus, the appropriate version of this equation for a competitive firm is simply price equals to marginal costs. However, a monopolist will never choose to operate where the demand curve is inelastic. For if $|\varepsilon| < 1$, then $\frac{1}{|\varepsilon|} > 1$, and the marginal revenue is negative so it cannot possibly equal to marginal cost. Therefore, any point where $|\varepsilon| < 1$ cannot be a profit maximum for a monopolist as it could increase its profits by producing less output. It follows that a point that yields maximum profit can only occur where $|\varepsilon| \geq 1$. In addition, it is assumed that ε is a declining function of c_i, which make sure the assumption of downward-sloping demand curves is valid, so that with an increase in quantity demanded, the price elasticity of demand will go down, i.e., $\frac{d\varepsilon}{dc} < 0$. On the other hand, with the only factor of production being labour and w is the labour wage, the total costs of the firm are $wl = w(\alpha + \beta x)$, so marginal cost will be βw. Therefore, in the short run:

$$p_i(1 - \frac{1}{\varepsilon(c_i)}) = \beta w \tag{4.6}$$

Thus, we have:

$$\frac{p_i}{w} = \frac{\beta \varepsilon(c_i)}{\varepsilon(c_i) - 1} \tag{4.7}$$

Using the assumption that ε is a declining function of c_i, $\frac{d\varepsilon}{dc} < 0$, equation (4.7) shows that $\frac{p_i}{w}$ and c_i are positively related. The relationship is shown by curve PP in Figure 4.2. Under the profit-maximizing equilibrium condition, when the individual firm experiences a higher demand for its products, the firm can obtain a higher price in the market. Therefore, the slope of PP is positive. In other words, since price rises with c_i, that will give the firm more monopoly power.

4.2.3 Long Run equilibrium of a Monopolistically Competitive Firm

In the long run, another characteristic of monopolistic competition is zero profits. This is implied by the assumption of freedom of entry and identical costs - if a firm's profits are positive, new firms will enter the marketplace and the profits are driven to zero. In equilibrium, the total revenue (TR) equals to total cost (TC). Since total revenue is equal to the price times output, total cost will equal the wage rate w times labour input, namely, $wl = w(\alpha + \beta x)$.

Therefore:

$$p_i x_i = w(\alpha + \beta x_i) \tag{4.8}$$

Substituting equation (4.3) into equation (4.8), we obtain:

$$\frac{p_i}{w} = \frac{\alpha}{Lc_i} + \beta \tag{4.9}$$

From equation (4.9), it can be seen that $\frac{p_i}{w}$ and c_i, vary inversely. The relationship is shown by curve ZZ in Figure 4.2. An increase in c_i, will lower the price therefore the slope of ZZ curve is negative. The intersection of ZZ with PP yields equilibrium levels of per capita consumption and price, c^* and $\frac{p^*}{w^*}$.The equilibrium output is $x^* = c^* L$.

We assume that there is symmetry in both production and consumption so that the prices and outputs of each of the firms will be the same. Henceforth, we drop the subscript i from p, x and c.

Finally, to determine the number of goods produced we use the condition of full employment. Substituting equation (4.2) and equation (4.4), we obtain[55]

$$n = \frac{L}{l} = \frac{L}{\alpha + \beta x} \tag{4.10}$$

Therefore, the number of goods produced is determined by the size of the total labour force and the amount of labour required to produce a representative variety. This completes the description of equilibrium in the economy. Next we use the model to investigate the impact of free trade.

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[55] Or divide the numerator and denominator of right hand side of equation 4.10 by L respectively, to obtain $n = \frac{1}{\frac{\alpha}{L} + \beta c}$.

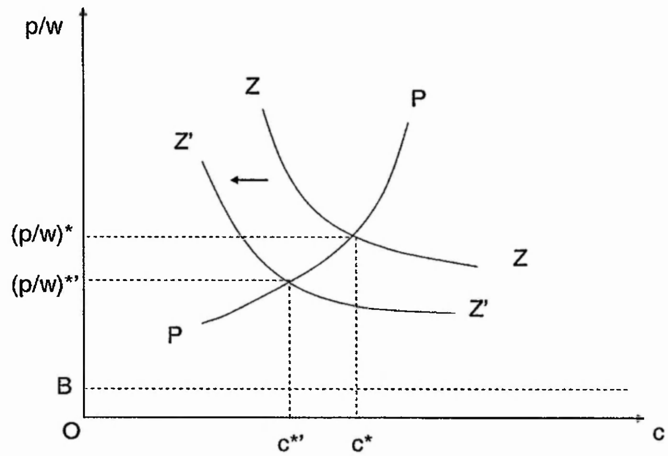

Figure 4.2 Equilibrium in the Krugman model

(Source : Krugman, 1979)

4.2.4 The Impact of Free Trade

The next consideration is the impact of trade on the initially closed economy. Assume there are two economies, *home country* and *foreign country* (denoted by an asterisk). They are identical in terms of tastes and technology but differ in size, with the size of labour force of the foreign country denoted as $L*$. If we assume there to be zero transportation costs, once trade opens up the firm will face a larger market and more consumers than before. From equation (4.7) we can see that β which reflects the relationship between input and output will not change because the technology is unchanged after the introduction of free trade, implying that the PP curve will not change. However, trade increases the aggregate number of consumers causing the ZZ curve to move leftward to Z'Z'. At the new point of equilibrium, (Z'Z'=PP), $\frac{p}{w}$ and c both go down. In the long run, x rises with the size of the labour force and now the relevant labour force is $L + L*$ and each product is produced at a larger scale. Gains from trade accrue on account of both scale economies and lower prices. In addition, from equation (4.11) below we can see that as the number of consumers increases from L

to $L+L^*$, and the consumption of each product drops from c^* to $c^{*'}$ variety has been increased, i.e., trade increases the sum of varieties. Since the consumer now has access to all $n+n^*$ varieties in the post trade equilibrium, the consumer's welfare rises on this account as well, so the gains from trade arise from increased access to variety as well as expanded scale of production.

$$n = n + n^* = \frac{1}{\dfrac{\alpha}{L+L^*} + \beta c^{*'}} \qquad (4.11)$$

Therefore, the following three important conclusions can be drawn from Krugman's (1979) model. First, there will be gains which result from increases in the scale of production, leading to lower unit costs and prices for monopolistically competitive firms. Second, although there is a decrease in the quantity consumed of each variety, consumers' welfare has increased due to an increase in varieties consumed, and finally, of course, the model predicts intra-industry trade even between identical economies.

A few aspects of the model need a little more consideration. First, based on the model which we have been discussing above, Krugman (1980) developed another basic model which can be viewed as a special case of his previous work. He replaces $v(c)$ by c^θ, where $0<\theta<1$ which implies that the utility function is of constant elasticity of substitution (CES) form.[56] In this case, ε is constant and equation (4.7) is sufficient by itself to determine the price in wage units. In terms of Figure 4.2, curve PP becomes a horizontal straight line. An increase in labour supply has no impact on $\frac{p}{w}$. Second, on the Krugman (1979) model, moving from autarky to free trade on each country is the same as that of an increase in labour force since these two countries are assumed to be identical in every respect. In the post-trade equilibrium, the quantity produced of each good and the associated price is the same across all products and across countries. This means that trade wages are also equalised across countries. The simplification introduced by the CES utility function was an important feature of Krugman's (1980) model and this was taken up in the following work by Lawrence and Spiller (1983).

[56] The constant elasticity case, however, is much easier to work with analytically, which is why I use it in this chapter, this means that there is no 'firm exit' effect when market integrated.

Lawrence and Spiller (1983) (henceforth 'LS') extended Krugman's model along two important dimensions. First, they allow for two factors of production, i.e., labour and capital. Moreover, they assume that the two trading partner countries have different initial factor endowments; one is capital abundant, the other is labour abundant. In addition two products are produced: (i) a horizontally differentiated good which is relatively capital intensive and produced under monopolistic competition, and (ii) a homogenous good which is labour intensive and which is produced under perfectly competitive market conditions. Second, when a firm wishes to enter the differentiated goods sector they have to incur significant initial capital outlays. These outlays could be thought of as fixed costs associated with the research and development required to differentiate products. In short, LS work is of great significance for the neo-Chamberlinian model, since most of the studies developed in this genre provide an explanation of trade which is independent of relative factor endowments. However, LS work allows economies to have different types of factor endowments. Using the LS framework, the following section develops an intra-industry trade model that incorporates measurement infrastructure.

4.3 Description of the Main Model

In this section we present a simple two-sector general equilibrium model where one sector is competitive and the other is monopolistic. This setup is relevant in that it allows us to model competitive advantage in the form of generating varieties, but also traditional patterns of comparative advantage. The model is closely related to those of Lawrence and Spiller (1983) and more recently Takahashi (2006). There are two factors of production, labour and capital, and these factors are assumed to be completely mobile. Our model differs from the above cited papers and indeed the rest of the literature such as Krugman (1979) and Helpman (1981), along two dimensions. First, we introduce into the model the concept of 'measurement-infrastructure' as discussed before to represent the strength of the public good affect at the level of the firm. This reduces what might broadly be termed transactions costs, lowering the costs of product differentiation and hence total costs. Second, use of the 'measurement infrastructure' (e.g., in making use of a standard) incurs costs in the form of instrumentation, which we call 'measurement capital'. Using this simple framework in what follows enables us to establish three important propositions. First, measurement infrastructure employed by the individual firm positively affects the number of varieties in the country in a

– closed-economy equilibrium. Second, as the number of varieties increase, their prices fall with consequential welfare enhancing effects on households. Third, opening up trade between two countries benefits both countries in that the overall volume of trade between them is bigger than in the absence of a measurement infrastructure. Hence intra-industry trade increases with measurement infrastructure but only up to a certain threshold beyond which it is not optimal for firms to deploy more measurement capital. To establish these propositions, we first consider the closed economy case, before moving on to the case of equilibrium trade with two countries.

4.3.1 A Closed Economy

Beginning with consumption patterns among households, consider a representative household maximizing utility according to a Dixit-Stiglitz (1977) 'love of variety' type preference:

$$U = Y^{1-s}\left(\sum_{i=1}^{n} x_i^{\theta}\right)^{s/\theta} \quad ; s < 1 \tag{4.12}$$

There are two types of good. A homogeneous good Y, produced under conditions of perfect competition, and a differentiable good x produced in n varieties. s and θ are parameters, with the latter related to the elasticity of substitution, σ, between any pair of Xi , by θ = (σ-1)/σ. In a richer environment than the one proposed here one can envisage measurement standards affecting utility. Nonetheless, as it is shown later, measurement-infrastructure affects the consumption pattern indirectly though the price mark-up.

The household obeys a budget constraint,

$$I = \sum_{i=1}^{n} p_i x_i + Y, \tag{4.13}$$

where income, I , is spent on the purchase of i differentiated goods with their respective prices, p_i, and the price of the homogenous good is normalized to unity. This is so as later we assume that the homogenous commodity Y is produced in a competitive market.

Maximizing (4.12) subject to (4.13) and with respect to x_i and Y yields, by standard methods:

$$p_i = \frac{sYx_i^{\theta-1}}{(1-s)\sum_i^n x_i^\theta} \tag{4.14}$$

The elasticity of demand between various differentiated goods is given by $1/(\theta-1)$ for large n. Imposing symmetry across households and assuming that they purchase goods in equal quantities, i.e., $x_i = x$ allows us to re-write (4.14) as:

$$p = \frac{sY}{(1-s)nx}. \tag{4.15}$$

Equation (4.15) is a typical downward sloping demand equation where a large number of varieties reduce willingness to pay for any given variety.

Turning now to firms, both goods are produced from private inputs. We assume that the output in the homogenous goods sector is produced competitively according to a Cobb-Douglas production function given by:

$$Y = K_Y^\varepsilon L_Y^{1-\varepsilon} \qquad 0<\varepsilon<1 \tag{4.16}$$

The amount of labour and capital used in the production of Y is L_Y and K_Y. For simplicity we assume that the homogenous good does not need any measurement capital. The firms take w and r - the unit cost of labour and capital respectively - as given, so that the profit maximization for a firm producing Y leads to the usual $MR = MC$ conditions:

$$\begin{aligned} \varepsilon Y &= rK_Y \\ (1-\varepsilon)Y &= wL_Y \end{aligned} \tag{4.17}$$

In the differentiated goods sector each variety i ($i = 1,...,n$) is produced by a single firm which gives it some monopoly power over its particular variety. However, the firm takes as given the prices for its primary inputs: capital and labour. Firms in this sector make use of the measurement infrastructure (e.g., the measurement related standards described in the previous section), indexed here by $0 \leq G < 1$ - which captures the overall level of measurement related activities taking place during the production process. For a firm using negligible measurement infrastructure $G = 0$. The use of the measurement infrastructure however also incurs capital costs (which typically take the form of instruments but may also involve additional expenditures required to conform to a given standard). There are therefore both benefits and costs of using the measurement infrastructure. While a strong infrastructure (loosely 'the public good effect' described in the last section) reduces conventional costs (such as marketing expenses), it requires a specific investment in the form of capital, such as measuring tools, testing equipment, technical documentation, voluntary industry agreements, all described by the function $Z(G)$. This function is a translator in that it gives the required quantities of measurement capital for a chosen level of G . We make two realistic assumptions about this function. First, firms in this sector must make use of a minimum amount of measurement capital (even when $G = 0$) implying $Z(0) > 0$. Second, greater use of the measurement infrastructure requires greater measurement capital investment, i.e., $Z'(G) > 0$. For simplicity we assume that arbitrage in various capital markets ensures that the unit price of capital that is affiliated with measurement activities is the same as that of other forms of capital[57]. Labour serves as the main variable input. Therefore, the cost function for the production of x_i can be written as:

$$TC_i = (1-G)^{\alpha}[r\gamma + w\beta x_i] + \text{rZ(G)},\ \alpha > 1;\ 0 \leq G < 1; Z'(G) > 0 \qquad (4.18)$$

The term in the square brackets on the right-hand-side gives the total cost of employing primary inputs, i.e., capital and labour. The first-term inside the square brackets is a fixed cost of employing capital and to simplify matters it is assumed that all firms use a fixed amount of conventional capital outlay γ. The second term is the variable cost of labour where, following Lawrence and Spiller (1983), the production function takes the simple form:

[57] This assumption keeps model tractable and helps bring out key points succinctly. However, one can imagine a situation in which both types of capital differ in prices and the firm may choose to exploit cost-savings by investing more on cheaper form capital.

$$x_i = \frac{1}{\beta} L_i, \tag{4.19}$$

The term $\frac{1}{\beta}$ is the marginal product of labour.

The term $(1-G)^{\alpha}$ - in (4.18) captures the idea that by using the measurement infrastructure G the firm takes away a fraction of its total primary input costs. The parameter $\alpha > 1$ implies diminishing returns to measurement infrastructure. The condition $G < 1$ is employed to ensure that the firms cannot do away with other factors of production by purely deploying some top level measurement infrastructure. The second term on the right-hand side in (4.18) is the cost of measurement infrastructure evaluated at r - the price of physical capital. For example, if we let $Z(G) = Q + FG$, as assumed in later calibrations, then Q, F denotes some fixed minimum level of measurement capital and a constant respectively. Note that when $G = 0$ there is no public good effect and the model collapses to that of Lawrence and Spiller (1983). To recap, the existence of a measurement infrastructure introduces costs savings in employing primary factors of production but also raises production costs and these two properties are the driving force behind the main results.

Assuming that each firm specializes in the production of one differentiated good, then the profit maximizing condition for our monopolist is at the point where $MR = MC$. By substituting the marginal costs from the total cost function, we obtain the following pricing equation for x_i

$$\frac{p}{w} = \frac{(1-G)^{\alpha}\beta}{\theta} \tag{4.20}$$

The optimal price is independent of the other competing varieties but is positively affected by the wage rate. This leads to our first proposition:

Proposition 1

Measurement infrastructure is welfare enhancing for consumers as it reduces the mark-up on wages. This happens due to the cost-saving effect of measurement infrastructure on hiring conventional factors of production.

It is important now to consider the impact of measurement infrastructure on product diversity. Assuming that there is a large number of n, a firm's entry into the industry X will drive profits to zero and the output produced by the representative firm (also the size of firm $i's$ plant in this model) using (4.20) is therefore:

$$x_i = \frac{r\theta\gamma}{\beta w(1-\theta)} + \frac{r\theta Z(G)}{\beta w(1-G)^{\alpha}(1-\theta)} \qquad (4.21)$$

Equation (4.21) says that the size of the plant of good x increases with $\frac{r}{w}$ ratio since fixed costs dominate variable costs. Capital outlays (γ) as well as measurement capital ($Z(G)$) also increase the size of production in that both can be viewed as fixed costs and more output is needed to recoup larger fixed costs. However, a marginal improvement in the infrastructure index, G , increases plant size only when the marginal benefit, in the form of lower variable costs, exceeds the marginal costs associated with greater measurement capital. These results require the frequently used condition that $\theta < 1$, which implies that the elasticity of demand is inversely related to price (as, for example, in the case of a linear demand curve). Next we turn to aggregation.

At a given point in time, the total stock of capital, $\bar{K}$, and labour, $\bar{L}$, in this economy are assumed fixed. The aggregate employment of capital and labour are therefore as follows:

$$\begin{aligned} \bar{L} &= L_Y + nL_x \\ \bar{K} &= K_Y + n\gamma \end{aligned} \qquad (4.22)$$

and L_Y, K_Y, L_X, $n\gamma$ denote the amounts of labour and capital used in the production of Y and the differentiated good respectively.

Using (4.17), (4.20), (4.21), and (4.22) we can obtain the total number of varieties of goods (i.e., the extent of product diversity in the economy):

$$n = \frac{\bar{K}s(1-\theta)}{\gamma[\varepsilon(1-s)(1-G)^{\alpha} + s(1-\theta)] + Z(G)\varepsilon(1-s)} \qquad (4.23)$$

Product variety is therefore inversely related to the extent of capital outlays (γ) and measurement capital ($Z(G)$).We cannot specify the equation of $\frac{d^2n}{dG^2} < 0$. However, with the linear function $Z(G) = Q + FG$ it is possible to show that $\frac{d^2n}{dG^2} < 0$.[58] Thus, the relationship between product diversity and the underlying measurement infrastructure (G) is concave. Indeed, using equation (4.23) with $Z(G) = Q + FG$ and differentiating with respect to G, the first-order condition for obtaining the maximum n is,

$$\alpha\gamma(1\text{-G})^{\alpha\text{-}1} = \text{F} \qquad (4.24)$$

This condition says that the firm should increase its investment in measurement capital until the marginal costs of doing so outweigh the marginal benefits. The left-hand side in (4.24) is the marginal benefit from increasing the measurement capital in the form of the reduction in the cost of investment on capital outlays and is governed by the parameter α. The concavity between the pair (n, G) is due to ($0 \le G < 1$). The right-hand side is the marginal cost of installing measurement capital for a given level of measurement infrastructure. By inverting (4.24) we obtain the underlying measurement infrastructure $G^* = 1 - (F / \alpha\gamma)^{\frac{1}{\alpha-1}}$ that maximizes product diversity. Note that for (4.24) to hold, the optimum level of measurement infrastructure and capital outlays have to move in the same direction. We therefore can state our second proposition.

Proposition 2

The relationship between product diversity (n) and the measurement infrastructure is concave. In equilibrium, the marginal benefit of an extra unit of measurement infrastructure, in the form of a cost reduction in capital outlays, is equal to its marginal cost.

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[58] Mathematic details refer to my second supervisor Dr. Ali Choudhary.

Intuitively, although the relationship between the product diversity and measurement infrastructure is concave, it seems likely that actual observations of the pair (n, G) would display a positive correlation as we find in the empirical section. Not least, this is because of the public good nature of the measurement infrastructure which suggests under-provision of infrastructure.

4.3.2 The Open Economy

We now consider trade between two economies – Home and Foreign - which are endowed with similar underlying consumer behaviour and firm technologies. Once again we examine the consumer problem followed by that of the firm, but must first distinguish between the two economies.

The standard assumption in the literature is for preferences to be identical between the two economies. The utility functions of the consumers in each country can therefore be written as:

$$\begin{aligned} U &= \overline{Y}^{1-s}\left(\sum_{i=1}^{n}\overline{x}_{hi}^{\theta}+\sum_{i=1}^{n}\overline{x}_{fi}^{\theta}\right)^{s/\theta} && \text{Home} \\ U^{*} &= \overline{Y}^{*1-s}\left(\sum_{i=1}^{n}\overline{x}_{fi}^{*\theta}+\sum_{i=1}^{n}\overline{x}_{hi}^{*\theta}\right)^{s/\theta} && \text{Foreign} \end{aligned} \tag{4.25}$$

Where the asterisks (*) refer to the foreign country and the bar over variables refers to consumption of each good. The subscripts h and f denote home and foreign production respectively. Thus, $\overline{x}_{fi}^{*\theta}$. denotes the consumption in the foreign country of variety i , and $\overline{x}_{hi}^{*\theta}$ refers to the foreign consumption of variety i with the goods produced in the home country. Assuming that varieties produced in home and foreign countries are n and n^*, then in equilibrium each country will balance demand with supply such that:

$$\begin{aligned} P_h n\overline{x}_h + P_f n^*\overline{x}_f + \overline{Y} &= P_h nx + Y && \text{Home} \\ P_f n^*\overline{x}_f + P_h n\overline{x}_h + \overline{Y}^* &= P_f n^* x^* + Y^* && \text{Foreign} \end{aligned} \tag{4.26}$$

The first-term on the left-hand side is the home country's consumption of home products and the second-term is the value of the home consumption of foreign products. On the right-hand side we have the value of the n differentiated goods and the homogenous good produced in the home country. Equation (4.26) implies that trade is balanced between the two countries.

The first-order conditions from utility maximization are:

$$P_i = \bar{y}\frac{s}{1-s}\frac{x_{1i}^{\theta-1}}{\sum x_{1i}^{\theta}+\sum x_{2j}^{\theta}}$$
$$P_j^* = \bar{y}^*\frac{s}{1-s}\frac{x_{2j}^{\theta-1}}{\sum x_{1i}^{\theta}+\sum x_{2j}^{\theta}} \tag{4.27}$$

Imposing symmetry in outputs and prices across monopolistically competitive firms, the pricing equation becomes:

$$P = \bar{y}\frac{s}{(1-s)(n+n^*)\bar{x}} \tag{4.28}$$

Using the same procedures as for the closed economy, the profit maximization solution for the differentiated goods is given by:

$$P = \frac{\beta w(1-G_h)^{\alpha}}{\theta}$$
$$P^* = \frac{\beta w^*(1-G_f)^{\alpha}}{\theta} \tag{4.29}$$

Similarly, the profit maximization problem in the competitive sector yields the following first-order conditions:

$$w = (1-\varepsilon)k_Y^{\varepsilon} \qquad w^* = (1-\varepsilon)k_Y^{*\varepsilon}$$
$$r = \varepsilon k_Y^{\varepsilon-1} \qquad r^* = \varepsilon k_Y^{*\varepsilon-1} \tag{4.30}$$

The zero profit condition implies that the output produced in each country in the differentiated goods sector is[59]:

$$x = \frac{r\theta\gamma}{\beta w(1-\theta)} + \frac{r\theta Z(G)}{\beta w(1-G)^{\alpha}(1-\theta)}$$
$$x^* = \frac{r\theta\gamma}{\beta w(1-\theta)} + \frac{r\theta Z(G)}{\beta w(1-G)^{\alpha}(1-\theta)} \tag{4.31}$$

The interpretation of equations (4.27) – (4.31) is similar to that discussed in the closed economy and so will not be repeated here.

4.3.3 International Trade

The implications of measurement infrastructure for international trade are now considered. To simplify exposition, the following relations are as in Lawrence and Spiller (1983):

$$\overline{K}^* = a\lambda K \quad \overline{L}^* = (2-a)\lambda L \quad 0 \leq a \leq 1 \text{ and } \lambda > 0 \tag{4.32}$$

Where the term a is a measure of the capital-labour differential and λ is a measure of the size of the foreign country relative to the home country. Using these relations, the world capital and labour stock can be defined as:

$$K_W = \overline{K} + \overline{K}^* = (1 + a\lambda)\overline{K}$$
$$L_W = \overline{L} + \overline{L}^* = (1 + (2-a)\lambda)\overline{L} \tag{4.33}$$

The international capital labour ratio is independent of measurement infrastructure and is given by:

$$\overline{k} = \delta k, \quad \delta = \frac{[1 + a\lambda]}{[1 + (2-a)\lambda]}, \tag{4.34}$$

[59] In the absence of frictions such as taxes or tariffs the solution is symmetric; as there will be factor- price equalization. Moreover, the size of plants will be equalized. P equal to P^*, w equal to w^*, r equal to r^*, k_y equal to k_y^*, x equal to x^*.

Where k denotes the capital-labour ratio of the home country. The labour and capital endowment constraints for firms in each industry are:

$$\begin{aligned}
\bar{L} &= L_Y + nx\beta, \\
\bar{L}^* &= L_Y^* + n^* x^* \beta, \\
\bar{K} &= K_Y + n\gamma_g, \\
\bar{K}^* &= K_Y^* + n^* \gamma_g, \\
G_f &= G_h = G.
\end{aligned} \tag{4.35}$$

The interpretation of the constraints is similar to before. However, the last condition assumes that both countries have similar levels of measurement infrastructure. We believe that this simple formulation displays many important features within the European markets where – in principle - firms in different countries have access to similar measurement infrastructures. Many features of our model are similar to those of Lawrence and Spiller (1983). For example, the total number of varieties produced in the world is the same in either open or autarchic equilibriums - holding constant the level infrastructure G. Therefore, there are no firm exit effects as in some models. However, the distribution of the production of varieties depends upon capital intensities between countries, and hence the initial pattern of comparative advantage.

To motivate the empirical analysis, the effect of measurement infrastructure on trade is now considered. Two new results can be established in the context of intra-industry trade. We examine these in turn.

4.3.4 Trade Volumes

In order to analyse the effect of interrelation between trade and infrastructure, it is necessary to consider the volumes of differentiated goods both produced and consumed, concentrating here on the differentiated goods sector which is directly affected by measurement infrastructure. In order to obtain the output produced in the differentiated goods industry, the international wage rental-cost-of-capital and capital labour ratios are substituted into (4.30) to obtain:

$$X = X^* = \left(\frac{\theta\gamma}{\beta(1-\theta)} + \frac{\theta Z(G)}{\beta(1-G)^{\alpha}(1-\theta)} \right) \frac{1}{\varphi \bar{k}},$$
$$\varphi = \frac{[s\theta + (1-\varepsilon)(1-s)(1-G)^{\alpha}][\gamma(1-G)^{\alpha} + Z(G)]}{(1-G)^{\alpha}\{\gamma[s(1-\theta)+\varepsilon(1-s)(1-G)^{\alpha}] + Z(G)\varepsilon(1-s)\}} \qquad (4.36)$$

As before for the autarchic case, the size of the firms producing the differentiated good increases with the level of measurement infrastructure only when the marginal benefit outweighs the direct marginal cost of investment on measurement capital; a result we also saw earlier. In addition, the size of any X firm is inversely related to the international capital-labour ratio because any rise in k will lead to increased variable costs.

Using the total number of differentiated goods in the world along with the home country's share of world income given by

$\pi = z\bar{K}/(\bar{K}+\bar{K}^*) + (1-z)\bar{L}/(\bar{L}+\bar{L}^*)$, where $0 < z < 1$ is the capital share of income, the post-trade level of consumption in industry X is obtained by

$$\bar{X} = \frac{\theta \bar{L}[z+(1-z)\delta][\gamma(1-G)^{\alpha} + Z(G)]}{\varphi\delta\beta(1-G)^{\alpha}\bar{K}(1-\theta)(1+a\lambda)} \qquad (4.37)$$

The trade surplus obtained by subtracting equations (4.37) and (4.36) simplifies to

$$\Delta X = X - \bar{X}$$
$$= \frac{\theta}{(1-\theta)} \frac{\gamma}{\beta} \frac{1}{\varphi\delta k} \{ \frac{\gamma(1-G)^{\alpha}(1+a\lambda) + Z(G)(1+a\lambda) - [z+(1-z)\delta][\gamma(1-G)^{\alpha} + Z(G)]}{(1-G)^{\alpha}(1+a\lambda)} \qquad (4.38)$$

The next step is to find out what happens to this trade surplus at different levels of measurement infrastructure. To simplify matters, let both economies have the same size so that $a = \lambda = \delta = 1$ and assume there are no endowment advantages. Furthermore, assume $Z(G) = Q + FG$, $Z(0) = Q$, for which the level of measurement infrastructure is maximizing n given by $G^* = 1 - \left(\frac{F}{\alpha\gamma}\right)^{\frac{1}{\alpha-1}}$. Now let us numerically compare the trade surplus at the optimal G^* and $G = 0$ (i.e., the minimum required infrastructure).

$$G^* : \Delta X^* = \frac{\theta}{2(1-\theta)} \frac{1}{\beta k} \frac{\gamma[s(1-\theta) + \varepsilon(1-s)(1-G)^\alpha] + Z(G)\varepsilon(1-s)\}}{[s\theta + (1-\varepsilon)(1-s)(1-G)^\alpha]} \tag{4.39}$$

And

$$G = 0 : \Delta X = \frac{\theta}{2(1-\theta)} \frac{1}{\beta k} \frac{\gamma[s(1-\theta) + \varepsilon(1-s)] + \varepsilon Q(1-s)\}}{[s\theta + (1-\varepsilon)(1-s)]} \tag{4.40}$$

The expressions (4.39) and (4.40) are not easily comparable. However if we set values[60] for the parameters $\gamma = 0.50, \varepsilon = 0.4, s, \theta, F, G = 0.5, Q = 3, \alpha = 2$ which satisfy the conditions for the optimization, we find that at the level of infrastructure G^* the volume of trade is 72% bigger between the two countries, as shown in Figure 4.3. Furthermore, holding all constant, a rise in the relative country size also positively affects the trade surplus, $\partial(\Delta X)^* / \partial\lambda > 0$. This leads to our final proposition.

Proposition 3

Compared with the situation where measurement infrastructure is minimal, raising the level of infrastructure towards the level at which variety is maximised also raises intra-industry trade between two equally endowed countries. This happens because a measurement infrastructure promotes product diversity, increases plant size and also reduces price mark-ups.

[60] With the exception of 'F' and 'G' the remaining data is taken from Lawrence and Spiller (1983).

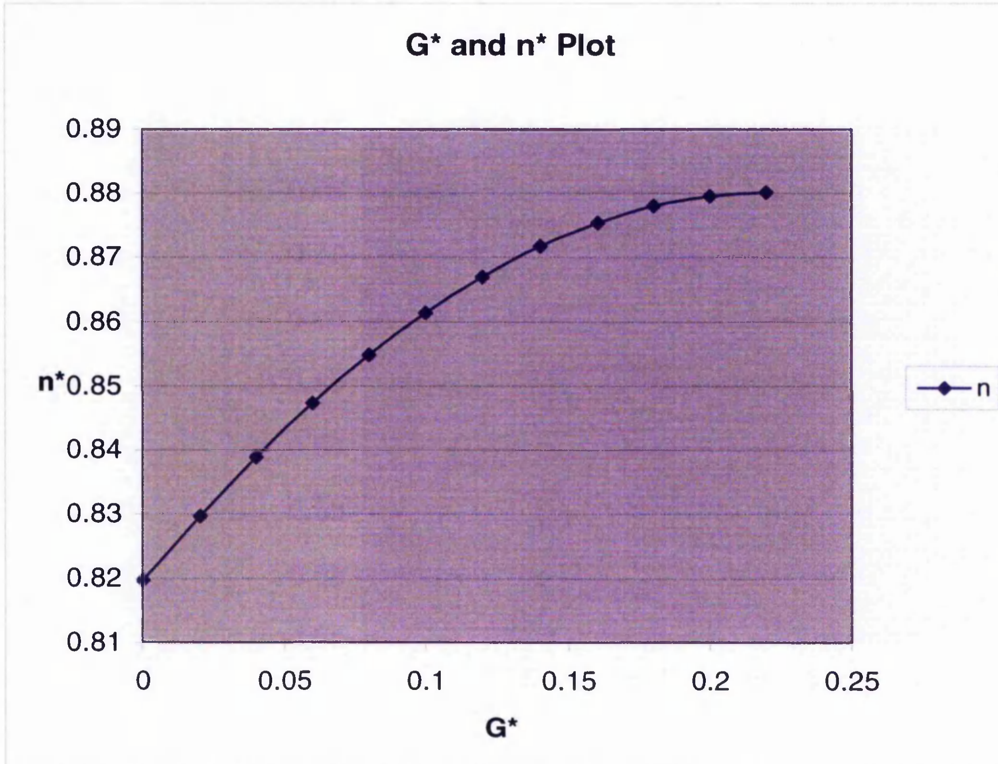

Figure 4.3 The level of measurement infrastructure, and product varieties

Figure 4.3 illustrates the relationship between the level of measurement infrastructure (G*) and product varieties (n*) with a clear positive relationship between the two variables. Along with the level of measurement infrastructure increase, due to its public good effect of the measurement infrastructure, the number of product variety increases and then achieves its maximised level, as shown in the upward trend in Figure 4.3.

4.4 Conclusion

This chapter first provided an overview of different theoretical trade models, before focusing on a review of two important models, namely Krugman (1979) and Lawrence and Spiller (1983). These are used in this study as a basis for a model specifically relating measurement to trade. The model developed differs from Krugman (1979) - and in this way it is similar to Lawrence and Spiller (1983) - in presenting a general equilibrium model of a two-sector economy, in which one sector is competitive (producing a homogenous good), while the other is monopolistically competitive (producing differentiated goods). Additionally, Lawrence and Spiller (1983) specify differences in factor endowments between countries, and assume that there are significant fixed costs in the form of a capital requirement before firms may enter the differentiated goods sector. This study builds upon this framework by specifying that investments in measurement are required as a prerequisite to introducing any new variety. These investments are related to the strength of the underlying measurement infrastructure which impacts on the firms' cost structures. In turn, the chapter has looked into the case when the level of measurement infrastructure is both identical and different between two trading countries. It is shown that there is a strong link between measurement infrastructure and the level of product diversity. First, in a closed economy equilibrium, the extent of measurement infrastructure available to the individual firms positively affects the number of varieties in the country. Second, as the number of varieties increase, as also shown, prices decline with resulting welfare enhancing effects on consumers. Third, the movement from autarchy to free trade will benefit both countries. Although the pattern of trade between the two trading countries with similar measurement infrastructure remains unchanged, the overall volume of trade between them is bigger than the situation with minimal infrastructure. Hence intra-industry trade increases with measurement infrastructure.

To summarise, the model suggests that there is a positive relationship between the sophistication of measurement infrastructure and the level of intra-industry trade over and above that which is dependent upon the impact of market size. The next chapter will empirically analyse the theoretical results.

Chapter 5

Econometric Models of Intra-Industry Trade at the EU Level

5.1 Introduction

The empirical literature on international trade has pursued two main paths. The first is the analysis of the determinants of comparative advantage. The role that measurement plays in the determination of comparative advantage in the case of the UK is pursued in the next chapter. The second path has been the empirical counterpart of theories explaining intra-industry trade (IIT) - the simultaneous import and export of products that fall in the same industry classification. IIT has grown rapidly, in particular trade among industrialized countries since at least the 1960s. The literature review and theoretical analysis of IIT were surveyed in chapters 3 and 4 respectively. They considered a considerable research effort regarding the causes, determinants and welfare implications of IIT. As we saw in these chapters, the theoretical models supplied by 'new trade theory' emphasized product differentiation within the context of scale economies and monopolistic competition as key characteristics explaining intra-industry trade. Accordingly, the empirical studies motivated by the development in theoretical work have been mainly concerned with testing the relevance of both industry-specific factors such as product differentiability and scale economies, as well as the country level factors relating to the size of markets and dispersion in market size between trading partners as determinants of IIT.

Along with greater understanding of the economics of industrial evolution and economic growth, increasing numbers of economists have accepted that technology plays a central role as an engine of growth. In this regard, international trade theory has increasingly concerned itself with the analysis of the impact of technological change and during the last few decades a growing literature has contributed to this area[61]. Somewhat surprisingly therefore, the role played by technological change has not generally shaped the empirical work on IIT, except in so far as technology helps determine in a rather static way the differences between industries. In particular the role played by what has been defined in chapter 2 as 'infra-technology' has been neglected. This is perhaps surprising since, as we have seen, especially in modern economies, the measurement infrastructure is an important element in these infra-technologies. Moreover as we also saw in chapter 2, there is a close relationship between metrology, and the institutions and sectors supporting measurement, and Swann's idea of a "pool of feasible measurements" (Swann, 1999). The two particular forms of support discussed in that chapter and of importance in the empirical analysis of this are the role played by technical standards, and the role played by the instrument sector of a modern economy. The specific hypotheses examined in this chapter draw on the predictions of the theoretical models developed in chapter 4, providing estimates of the relationship between measurement infrastructures and intra-industry trade. The estimates in this chapter are confined to intra-EU trade prior to enlargement. The main reason for restricting the analysis in this way is to consider the idea of a common measurement infrastructure. Here the role of a common set of measurement related standards has arguably been an important element in the development of economic policy across the EU as it stood in 1980s and 1990s. Thus the econometric models are based on the trade flow data for EU 15 countries. These were collected for 1998 for 22 manufacturing sectors.

The econometric analysis in this chapter is based upon the large corpus of literature that now exists concerning the determinants of intra-industry trade. It shows that explanatory variables suggested by the monopolistic competition model of trade are important but need to be supplemented by other factors which are also important determinants – such as the distance between economies, or the existence of a common border at the level of countries, or 'product differentiability' at the level of individual industries. This chapter augments this

[61] The major theories of trade refer to Posner 1961, Hufbauer, 1966 and Vernon 1966.

framework by adding the measurement related variables suggested in earlier chapters in the context of bilateral trade in the EU. This is achieved by adding – as an additional variable at the industry level – the size of the stock of 'measurement related' industrial standards as discussed in chapter 2. Here it was seen that standards provide an idea of the amount of measurement related 'codified knowledge' in the form of technical specifications that are available. This source of information consists of "technical documents providing information regarding test methods, reference materials and so forth and provide an important public good element to product differentiability. A count of such standards provided us with a means of evaluating the relative importance of this infrastructure across industries" (Temple, *et al.*, 2006). Since these standards are available and marketed nowadays throughout the EU, bilateral trade within the EU seems to be an appropriate object of study.

However, it is not clear that the availability of standards indicates that all EU countries have equal access to the measurement infrastructure implied by the standards count. This chapter therefore also considers the addition of variables describing possible cross country variation in the importance of measurement as a determinant of IIT. Chapter 2 suggests this may be done by examining the extent of instrument use across countries.

The organization of the chapter is as follows. Section 5.2 considers the existing econometric literature on intra-industry trade. Section 5.3 considers the implementation of the framework in the EU context, providing data description and discussion. Empirical results and relevant discussion are presented in section 5.4 and the final section 5.5 provides a conclusion for this study.

5.2 The Econometrics of Intra-Industry Trade

As previously discussed, the empirical measurement of intra-industry trade started during the 1960s (Balassa (1966), Grubel and Lloyd (1975), the theoretical models of explanations such as Krugman (1979, 1981); Lancaster (1979); Helpman (1981); Helpman and Krugman (1985) and Helpman (1987) were developed later). A large econometric literature has also grown up examining the determinants of intra-industry trade. This section examines that literature in order that an appropriate specification for an econometric model to test the main hypothesis about the role of measurement can be addressed. Accordingly, this section is organized as follows. First, the measurement of the dependent variable - intra-industry trade with its logit transformation will be introduced. After that, based on several international trade theories, i.e. monopolistic competition, the Linder hypothesis and comparative advantage, the measurement and other issues surrounding the independent variables relating to the testing of theoretical hypotheses will be investigated.

5.2.1 The Measurement of IIT

The bulk of the econometric studies of IIT have used various measures of IIT, usually based upon the Grubel-Lloyd ('GL') index, and regressed them against a set of variables representing the determinants. The basic Grubel-Lloyd index measures the extent of intra-industry trade (Grubel and Lloyd 1975). For any particular country pair h, f, intra-industry trade for any given industry i the index is given by :

$$IIT_{hfi} = \left[1 - \frac{\left| X_{hfi} - M_{hfi} \right|}{\left(X_{hfi} + M_{hfi} \right)} \right] * 100 \text{ and } 0 \leq IIT_{hfi} \leq 100 \qquad (5.1)$$

Where:

IIT_{hfi} is the i industries at a given level of statistical aggregation,

X_{hfi} is the value of the exports of industry i for country h to country f.

M_{hfi} is the value of the imports of industry i for country h from country f.

The closer IIT_{hfi} is to 100, the greater the importance of intra-industry trade. The closer IIT_{hfi} is to zero, the greater the importance of inter-industry trade.

Grubel and Lloyd then recognized that total trade imbalance (surplus or deficit) might influence the measurement of IIT, which may result in an underestimate of the extent of IIT. They suggested an alternative GL index to adjust for the trade imbalance. In addition, there are still different views by trade economists such as Balassa (1974), who attempted to develop explicitly an index that can measure the extent of intra-industry trade. Balassa (1974) considered an alternative formula to measure intra-industry trade, taking the sum of the ratios of trade balances to total trade for each product group and then dividing by the number of product groups. In addition, Glejser *et al* (1979) suggested another approach in estimating IIT in the European Community, with its key advantages in the consideration of IIT in different countries over time. But Greenaway and Milner (1986) indicated that the method should be used carefully since it concentrates too much on comparative performance. In addition, Grimwade (2001) has argued that the trade relative difference in IIT measured by the formula only considers the trade flows between countries rather than domestic production or sales[62].

In summary, the GL index, along with other transformed formats, provide useful tools in measuring IIT between countries. As shown in equation 5.1, the GL index reflects the relationship between import and export trade flows at two countries or multi-countries level. The index takes values from 0 to 1 as the extent of intra-industry trade increases. However, if regression estimation is made by using a linear or log-linear function, the predicted values may exceed one or even negative (Balassa and Bauwens, 1987). In order to map the original range (0, 1) of GL index into the range (-∞, +∞), a logit transformation has widely been used in many studies. The formula can be expressed as:

$$Trans\_IIT_{hfi} = Log[IIT_{hfi} / (1 - IIT_{hfi})] \qquad (5.2)$$

Where:

$Trans\_IIT_{hfi}$ is the transformed IIT_{hfi} by logit function;

IIT_{hfi} is the raw calculated GL index, or other alternative index.

[62] In addition, the last few years' intra-industry trade has been linked with the factor market adjustment. Many economists started to discuss the wobbly foundations of the "smooth-adjustment hypothesis". The supposition is that IIT entails lower costs of factor-market adjustment than inter-industry trade, referred to here as the smooth-adjustment hypothesis (Brulhart, 1999). They believe along with the growing intra-industry trade, the adjustment costs such as frictional unemployment, wage dispersion or labour turnover and so on should be considered. Nonetheless the GL index is a static measure, in order to capture the impact of adjustment cost in the dynamic phenomenon; they suggest the marginal IIT index should be used. See e.g. Hamilton-Kniest, 1991; Greenaway *et al*, 1994; Brulhart, 1994; Menon and Dixon, 1997 and Oliveras and Terra, 1997.

Suppose that IIT is represented by GL index, the formula (5.2) can be expressed as:

$$Trans\_GL_{hfi} = Log[GL_{hfi}/(1-GL_{hfi})] = Log(GL_{hfi}) - Log(1-GL_{hfi}) \qquad (5.3)$$

Although the logit transformation has the advantages of ensuring that predicted values are within the expected interval, this method cannot deal with values 0 and 1. As Balassa and Bauwens (1987) indicate, since the GL index of 0 and 1 represents complete inter-industry and intra-industry trade respectively, simply excluding those data will bias results due to the missing information of pure intra- or inter-industry trade, originally contained in the sample. But this method is still quite useful under the circumstance of no or at least an insignificant proportion of such observations. This is the case with the current data. Therefore, under the scope of the study, the logit transformation of the GL index will be reported and analysed in later empirical work[63]. Further consideration will be given to the measurement of IIT when reporting the results.

5.2.2 The Determinants of Intra-Industry Trade

While the measurement of IIT itself has been the subject of some debate, measurement issues relating to the independent variables may represent an obstacle to aligning empirical work with the theoretical models. As we have seen, different international trade theories have focused on different explanatory variables to explain intra-industry trade. Any econometric model attempting to explain intra-industry trade needs to be aware that many of the trade theories are complementary to each other. So in addition to the factors predicted to be important in the version of the monopolistic competition model discussed in the last chapter, other determinants need to be considered. The discussion in this section uses the literature on the determinants of intra-industry trade to determine appropriate controls for an econometric model, focussing on the measurement issues involved. These can be divided into four main genres, namely, economic development and the Linder hypothesis, the theory of monopolistic competition, the theory of comparative advantage and various ad hoc factors; these will be discussed in this section in turn.

[63] IIT have been divided into vertical and horizontal, which is no longer part of this thesis.

5.2.2.1 Economic development and the Linder hypothesis

It has been widely accepted that the importance of intra-industry trade tends to increase with the level of a country's per capita income. Closely related to this is the stage that a country has reached in its economic development (Grimwade, 2001). Economic development is deemed a determinant of intra-industry trade between two countries in two ways: (1) the stage of economic development; and (2) the extent to which they are at different stages of economic development. Loertscher and Wolter (1980) revealed several reasons to explain this relationship. First, highly developed countries have a high capability to innovate, which forms an important precondition to develop and produce highly differentiated goods. Second, these countries are characterized by a highly differentiated demand that allows for the exploitation of economies of scale in the production of a wide variety of individual commodities. Third, highly developed countries enjoy highly developed information and communication linkages. All these factors enlarge the scope for the realization and expansion of trade in highly differentiated products. Therefore for two highly developed economies - at a similar stage of economic development - the intensity of intra-industry trade will be greater. The most common variable used to capture this determinant is average per capita income. On the other hand, if countries differ in development levels and trade with each other, the result is more likely to be inter- rather than intra-industry trade. The level of intra-industry trade is lower for trade between economies at different stages of economic development. The absolute difference in the level of per capita income is the most common variable used to capture this determinant.

As an indicator of per capita income, most studies use per capita GDP or GNP[64] and these enjoy strong empirical support. However it needs to be noticed that per capita income may influence the volume and pattern of intra-industry trade via both the demand and the supply side. The demand side refers to Linder Hypotheses that will be discussed later. On the supply side on the other hand, per capita income is likely to be closely correlated with an economy's overall capital-labour ratio and as such, related to monopolistic competition models. For example, in Helpman and Krugman's (1985) model, the differentiated good is assumed to be

[64] The difference between the two being net flows of property income.

capital intensive in production. A higher per capita income indicates a higher capital labour ratio, thus producing a greater production of capital intensive goods and more intra-industry trade. Differences in capital-labour ratios are of course (within a Heckscher-Ohlin framework for example) a determinant of comparative advantage and hence likely to be negatively related to intra-industry trade.

A number of studies have found that the extent of intra-industry trade is positively and statistically significantly correlated with average per capita income (e.g. Pagoulatos and Sorensen (1975); Loertscher and Wolter (1980); Balassa (1986a, b); Balassa and Bauwens (1987, 1988) and Nilsson (1999)).

However, as we saw in chapter 3, Linder[65] (1961) proposed that the international trade patterns in manufacturing are dependent on the similarity of preference among nations. He believed that countries have similar demands for manufacturing with others that have similar per capita income levels. In other words, per capita income can also be viewed as an indicator of demand structure, so that inequality between per capita income can also be viewed as a likely proxy for taste differences. The greater inequality in per capita income, the greater the dissimilarity in demand structures between two trading partners, decreasing intra-industry trade. Loertscher and Wolter (1980), Tharakan (1984), Culem and Lundberg (1986), Balassa (1986c), Helpman (1987), Lee (1989), Bergstrand (1990) and Nilsson (1999) have all found that there is a negative effect on bilateral intra-industry trade between countries.

Whatever the interpretation of these two variables, they clearly have received considerable empirical support in the literature and will be used in the empirical analysis of this chapter.

[65] The main- difference between the Linder hypothesis and economic development is that the former focuses on demand and the latter focused on supply.

5.2.2.2 According to the Theory of Monopolistic Competition

Some theoretical variables such as market size, product differentiation, scale economies and market structure relate to the monopolistic competition model, and have been employed by many trade economists to determine the extent of intra-industry trade.

Market Size

The monopolistic competition model is of course based upon increasing returns, so that market size is deemed a determinant of intra-industry trade between two countries, in two ways as well: (1) the aggregate (or average size) of the markets of the two countries; and (2) the difference in the size of the two countries.

In general, the average and the difference of countries' GDP or GNP are used to reflect the averages and differences of market size in most empirical studies. The greater the GDP or GNP indicates the greater economic size of a country, suggesting the greater potential production of a larger number of products under increasing returns to scale. In addition, producers in large countries will enjoy lower average costs than producers in small countries. These countries are therefore more likely to specialise in differentiated goods in which intra-industry trade is more important than inter-industry trade. Many studies have found empirical support for the hypothesis that the extent of intra-industry trade is positively correlated with the average size of a country as measured by GDP or GNP. These include Loertscher and Wolter (1980), Balassa (1986a, 1986b), Balassa and Bauwens (1987, 1988), Bergstrand (1990), Nilsson (1999) and Clark and Stanley (1999, 2003). As far as the differences between economic size, Helpman (1981), Loertscher and Wolter (1980), Balassa (1986c), Culem and Lundberg (1986), Bergstrand (1990) and Nilsson (1999) have all found IIT to be negatively correlated with differences in country size.

However, data on GDP or GNP may not provide an entirely satisfactory proxy for market size since it does not have an industrial dimension. For instance, Germany has a bigger GDP than Italy, but Italy almost certainly has a bigger market size for pasta and perhaps wine. A preferable measure of market size is therefore the value of production or consumption measured at an industrial level. Based on these considerations, both market size indicators (GDP and value of industrial production) are used in this chapter's econometric estimation.

Product Differentiability and Heterogeneity

Product differentiation has long been recognized as a basis for intra-industry trade to occur. In principle therefore, variation in the extent to which products are differentiable across industries should assist in determining the extent of intra-industry trade. However attempts to measure product differentiation have varied in the literature. The following four proxies have all been used for empirical work to measure the degree of product differentiation at an industrial level: (1) product heterogeneity; (2) Hufbauer index; (3) advertising-sales ratio and (4) R&D intensity.

Product heterogeneity has sometimes been measured by the number of commodity sub-groups within a single three-digit product classification. Pagoulatos and Sorensen (1975), Caves (1981), Greenaway and Milner (1984) and Hughes (1993) have all found the coefficient on such a measure of product heterogeneity to be positive and statistically significant. The results provided by Loertscher and Wolter (1980) are positive and insignificant. However, Tharakan (1984) found the coefficient of product differentiation to vary between different years and to be statistically insignificant. Strictly however it is clear that product heterogeneity is not the same concept as differentiability and the sub-groups may be referring to quite different types of goods produced possibly by different techniques. It may for example be considered as providing a measure of the extent to which any given industrial grouping is prone to aggregation bias – aggregating instances of inter-industry trade determined by both comparative advantage and comparative disadvantage into apparent intra-industry trade.

Hufbauer (1970) uses the coefficient of variation of export unit values as a measure of product differentiation[66]. The idea here is that highly homogeneous products will not support

[66] Hufbauer index for industry $H = \sigma_{ih} / M_{ih}$, where σ_{ih} is standard deviation of export unit values for shipments of goods i to country h; and M_{ih} is the average of the unit values.

a wide variation in unit values, interpreted as prices. Toh (1982), Culem and Lundberg (1986), and Balassa and Bauwens (1987, 1988) found that there are positive and significant correlations between the Hufbauer index and intra-industry trade. By contrast Caves (1981) found a positive but insignificant impact for the Hufbauer index. Tharakan (1984) finds similarly that although the Hufbauer index varies between different regression years, it is statistically insignificant.

Product differentiability has also been associated with intensity in R&D and types of marketing techniques. New varieties must be developed and these varieties must be marketed in order to achieve customer awareness. To capture this intensity, ratios of R&D, purchased advertising, marketing other than purchased advertising, and sales costs relative to total sales have all been used .These variables are all assumed to vary positively with intra-industry trade. Caves (1981), Lundberg (1982) and Greenaway and Milner (1984) find that the coefficient for R&D expenditure is positive but insignificant. However, Hughes (1993) found coefficient for R&D expenditure is positive and significant for France, Germany, Italy and UK. As for the advertising-sale ratio, Greenaway and Milner (1984), Lee (1989), Balassa and Bauwens (1987, 1988), Clark (1993) and Clark and Stanley (1999, 2003) have found the advertising-sale ratio are positive and significant. The coefficient of advertising-sales ratio was however found to be negative but insignificant by Caves (1981). Although it has been used as a determinant of differentiability, it seems clear that R&D can also – as predicted in the technology gap literature for example – act in a way that creates inter-industry trade.

Scale Economies

The significance of the model of monopolistic competition stems from the existence of economies of scale and a resulting trade-off between variety and costs. In empirical work, a broad variety of proxies have been used to capture the effect of scale economies. Minimum efficient scale, usually measured by gross value added per employee in the largest five firms relative to gross value added per employee in the remaining firms is the most common proxy in many empirical studies. Using minimum efficient scale as a proxy for scale economies, Caves (1981), Greenaway and Milner (1984), Clark (1993) and Hughes (1993) have all found negative results, most results are insignificant, although Greenaway and Milner found strong significant support for the negative relationship. In addition, Loertscher and Wolter (1981) use value added per establishment as an indicator for economies of large scale and found it to be negative and significant. Likewise, Balassa and Bauwens (1987, 1988) also found that intra-industry trade was negatively correlated with economies of scale.

Other measures of economies of scale have included the share of labour force employed in big plants, such as Lundberg (1982) who used the share of labour force employed in big plants as proxies for scale economies, the estimation result showed that there is positive correlation with the statistic significant between intra-industry trade with economies of scale.

Market Structure

The relationship between market structure and intra-industry trade is an ambiguous one. High levels of intra-industry trade are predicted for example in some models of highly concentrated oligopolistic industries as well as in monopolistically competitive industries. Measures used in regression analysis as market structure proxies have included the domestic four or five-firm concentration ratio, an internationally adjusted concentration ratio.

The four or five-firm concentration ratio is a common proxy in most empirical studies which measures the share of total sales (or similar measure of industry size) accounted for by the largest domestic firms. Greenaway and Milner (1984) and Clark and Stanley[67] (1999, 2003) have found that the coefficients on the concentration ratio variables are negative and strongly significant. This simple measure can be adjusted to account for the fact that international competition reduces the market power of domestic firms. An internationally adjusted concentration ratio can be found by dividing the traditional domestic firm concentration ratios by the share of imports in industry output. Studies also using such a measure, such as Toh (1982), Balassa and Bauwens (1987, 1988) have also found that industrial concentration variables are negatively correlated with the extent of IIT and are highly significant statistically.

[67] Who used the top four firm seller concentration ratio.

5.2.2.3 Theory of Comparative Advantage

The law of comparative advantage has been used to explain intra-industry trade (Bergstrand 1990). Unlike the earlier one (section 5.2.2.1) on economic development which focused on the country provides high capability to innovate and produce differentiated products; this is more related to the factor endowment model. As noted above Bergstrand (1990) argued that the ratio of capital-to-labour in a country is closely related to an economy's stage of development - the more economically advanced a country, the greater the ratio of capital-to-labour, and (in line with the Heckscher-Ohlin model) the more likely it is to be specialised in more capital intensive goods. The empirical results show that the coefficient of average capital labour endowment ratio as being negative and statistically significant which implies that these manufactured products are labour intensive in production. As for the inequality between capital-labour ratio, the empirical results reported by Lee (1989) and Clark and Stanley (1999, 2003) show that the coefficient of difference capital labour ratio is negative and statistically significant. Bergstrand (1990) however finds that it is statistically insignificant.

5.2.2.4 Other Factors

Average nominal tariffs, common borders, distance and common language, etc., have been considered as other factors influencing intra-industry trade. The variability of tariff rates within an industry as well as between countries may be expected to influence the level of intra-industry trade. Balassa and Bauwens (1987), and Lee (1989) found some support for this hypothesis. The common border is generally measured for countries sharing a land boundary. Balassa (1986a); Balassa and Bauwens (1987, 1988); Bergstrand (1990); Loertscher and Wolter (1980) all found the coefficients on a dummy variable controlling for a common border are both positive and significant. Distance refers to a measure of the physical distance between trading partners and is frequently regarded as a proxy for transport costs. Balassa and Bauwens (1987), Loertscher and Wolter (1980), Pagoulatos and Sorensen (1975), Culem and Lundberg (1986), Balassa (1986c), Lee (1989), Nilsson (1999), Clark and Stanley (1999, 2003), Hummels and Levinsohn (1995), and Tharakan (1984) all adopted distance as a proxy for transport costs and show the negative and strong significant correlation between distances with intra-industry trade. Common language dummies have also been used in empirical studies – for example by Loertscher and Wolter (1980), Balassa and Bauwens (1987), who found positive relationships with varying levels of statistical significance.

In summary, this section has provided a review of the econometric work on explanations of IIT and has indicated how it has controlled a number of factors in addition to those suggested by the monopolistic competition model of IIT. However, previous studies have neglected to consider "infra-technology" in the form of measurement infrastructure, and the potentially important impact that it has on increasing the number of varieties. The next section considers how this factor can be incorporated into the specification for an empirical model suggested by the literature in the context of the EU.

5.3 Model Data

The preceding section suggested a commonly accepted framework for measuring the extent of IIT, as well as providing a review of the way the various explanations of IIT have been incorporated into a set of explanatory variables. Testing our own model therefore involves introducing our own specific hypotheses – regarding the role of measurement – into this existing framework – which may, on the basis of the model presented in chapter 4, suffer from omitted variable bias. This section considers both the measurement of IIT and the explanatory variables further in the context of intra-EU trade, describing the data collected and used in the regression models. A description of the trade data follows.

5.3.1 The Pattern of Trade in the EU

The bilateral IIT data used here have been taken from 14 of the 15 EU countries constituting the EU prior to enlargement (Belgium and Luxemburg are combined in the data) and has been collected for 22 manufacturing sectors based on OECD bilateral trade data (OECD 2000). A list of these industrial sectors is given in table 5.1. In total there are potentially 2002 trade flow observations. This is calculated as 14 (countries) ×13 (country partners) × 22 (industrial sectors) divided by 2 since half of the data needs to be removed due to $IIT_{ij}=IIT_{ji}$, where i is the export country and j is the country's trade partner. For each industry sector, there are 91 potential observations. Data are for 1998.

Among all observations, only three are with $X_{ijk}=M_{ijk}=0$, indicating that no trade takes place between two specific countries, where i, j are defined the same as in section 5.2.1 and k indicates industry sector. Nineteen are with $X_{ijk}=0$ and 13 are with $M_{ijk}=0$, both of which represent complete inter-industry trade between two countries. Only one is with $X_{ijk}=M_{ijk} \neq 0$, with the calculated GL index equal to 1 which indicates complete intra-industry trade.

Code	Industrial Sector	Code	Industrial Sector
1	Other Manufacturing	12	Non-Ferrous Metals
2	Professional Goods	13	Iron & Steel
3	Other Transport Equipment	14	Non-metallic Mineral Products
4	Aircraft	15	Rubber & Plastic Products
5	Motor Vehicles	16	Petroleum Refineries & Products
6	Shipbuilding & Repairing	17	Drugs & Medicines
7	Radio, TV & Communication Equipment	18	Chemicals excluding Drugs
8	Electrical Machinery	19	Paper, Paper Products & Printing
9	Office & Computing Machinery	20	Wood Products & Furniture
10	Non-Electrical Machinery	21	Textiles, Apparel & Leather
11	Metal Products	22	Food, Beverages & Tobacco

Table 5.1 List of Industrial Sectors in the Study

(Data Source: OECD, 2000)

Table 5.2 shows the geographical destination of total exports of intra-EU trade for 1998, expressed as a percentage of total exports based upon the 22 manufacturing industries. 11 countries, namely Austria, Belgium/Luxembourg, Denmark, Finland, France, UK, Greece, Italy, Netherlands, Portugal and Sweden had Germany as their biggest exports market highlighted in blue text in Table 5.2. Austria accounted for the highest percentage of export by value which is 57%, followed by Greece with 35%. For Germany itself, the highest proportion was to France with 20% of its total exports. Excluding Germany, the only countries whose main export partner was not Germany were Spain whose main export destination was France (28%) and Ireland, whose main partner was the UK, at 32%.

Year 1998			Exports to													
			AUT	BLX	DEU	DNK	ESP	FIN	FRA	GBR	GRC	IRL	ITA	NLD	PRT	SWE
Exports from	Austria	(AUT)	0%	3%	**57%**	1%	4%	1%	7%	7%	1%	0%	13%	4%	1%	2%
	Belgium/Lux	(BLX)	2%	0%	**26%**	1%	5%	1%	24%	13%	1%	1%	8%	16%	1%	2%
	Germany	(DEU)	10%	10%	0%	3%	7%	2%	**20%**	15%	1%	1%	13%	12%	2%	4%
	Denmark	(DNK)	2%	3%	**32%**	0%	3%	4%	8%	15%	1%	1%	6%	6%	1%	17%
	Spain	(ESP)	1%	4%	19%	1%	0%	0%	**28%**	12%	1%	1%	13%	4%	13%	2%
	Finland	(FIN)	2%	4%	**21%**	5%	4%	0%	9%	17%	2%	1%	7%	8%	1%	17%
	France	(FRA)	2%	12%	**26%**	1%	14%	1%	0%	16%	1%	1%	14%	7%	2%	2%
	UK	(GBR)	1%	9%	**21%**	2%	7%	1%	17%	0%	1%	11%	9%	13%	2%	5%
	Greece	(GRC)	2%	3%	**35%**	2%	5%	1%	9%	13%	0%	1%	21%	5%	1%	3%
	Ireland	(IRL)	1%	10%	23%	1%	4%	1%	12%	**32%**	0%	0%	5%	8%	1%	3%
	Italy	(ITA)	4%	5%	**29%**	1%	10%	1%	23%	13%	4%	1%	0%	5%	3%	2%
	Netherlands	(NLD)	2%	16%	**32%**	2%	4%	1%	14%	14%	1%	1%	8%	0%	1%	3%
	Portugal	(PRT)	1%	6%	**25%**	2%	18%	1%	18%	15%	1%	1%	5%	6%	0%	2%
	Sweden	(SWE)	2%	8%	**19%**	11%	5%	9%	9%	16%	1%	1%	7%	11%	1%	0%

Table 5.2 Geographical Pattern of Intra-EU Trade for Manufactured Exports 1998 (% of Export)

(Data Source: OECD, 2000)

Table 5.3 provides a similar table for imports – showing the percentage of total imports from each EU partner in 1998. Nine of the 14 countries ((Austria, Belgium/Lux, Denmark, Finland, France, UK, Italy, Netherlands and Sweden) imported the highest proportions of their imports from Germany as highlighted in yellow. Germany accounted for the highest percentage of imports by Austria (61%), followed by Italy (32%). For Germany, the highest percentage of imports was from France (18%), and then from Italy (15%). For Spain, the main source of imports was France with 27%, mirroring its main exporting destination. Countries whose main source of imports was not Germany were Greece whose largest source of imports was Italy at 27%, and the highest proportion of imports into Ireland was from the UK at 63%. Spain is Portugal's main source of imports, accounting for 32% of imports by value. Clearly, there are similarities between Tables 5.2 and 5.3, reflecting the greater economic size of Germany, as well as the potential importance of distance and/or a common border where Germany is not the major partner.

Year 1998			Imports to													
			AUT	BLX	DEU	DNK	ESP	FIN	FRA	GBR	GRC	IRL	ITA	NLD	PRT	SWE
Imports from	Austria	(AUT)	0%	1%	9%	2%	2%	2%	1%	2%	2%	1%	4%	1%	1%	2%
	Belgium/Lux	(BLX)	4%	0%	13%	6%	7%	6%	16%	10%	6%	3%	9%	19%	5%	6%
	Germany	(DEU)	61%	29%	0%	31%	23%	28%	29%	27%	21%	11%	32%	31%	20%	27%
	Denmark	(DNK)	1%	1%	3%	0%	1%	6%	1%	2%	2%	1%	1%	1%	1%	10%
	Spain	(ESP)	2%	3%	5%	2%	0%	2%	10%	5%	6%	2%	8%	3%	32%	3%
	Finland	(FIN)	1%	1%	2%	4%	1%	0%	1%	2%	2%	1%	1%	2%	1%	9%
	France	(FRA)	7%	21%	18%	9%	27%	8%	0%	17%	13%	8%	21%	11%	14%	10%
	UK	(GBR)	4%	13%	12%	12%	12%	12%	13%	0%	10%	63%	11%	17%	9%	16%
	Greece	(GRC)	0%	0%	1%	0%	0%	0%	0%	0%	0%	0%	1%	0%	0%	0%
	Ireland	(IRL)	1%	4%	4%	2%	2%	1%	2%	8%	1%	0%	2%	3%	1%	3%
	Italy	(ITA)	12%	6%	15%	7%	15%	7%	15%	10%	27%	4%	0%	6%	11%	6%
	Netherlands	(NLD)	5%	16%	13%	8%	5%	7%	8%	9%	7%	4%	7%	0%	4%	8%
	Portugal	(PRT)	1%	1%	2%	1%	4%	1%	2%	2%	1%	0%	1%	1%	0%	1%
	Sweden	(SWE)	2%	4%	3%	16%	2%	21%	2%	4%	3%	2%	2%	4%	2%	0%

Table 5.3 Geographical Pattern of Intra-EU Trade 1998 (% of Import)

(Data Source: OECD, 2000)

Table 5.4 presents the total export and import trade flows for aggregate trade of the 22 sectors in terms of export and import values. It shows a similar pattern to Tables 5.2 and 5.3. 11 countries have the highest value of exports to Germany and these are highlighted in blue; 9 countries have the highest value of import from Germany and these are highlighted in yellow. The biggest trading partners are France and Germany – shown in italics in Table 5.4. Germany is the biggest trading economy among 14 EU countries.

Year 1998			Exports to													
			AUT	BLX	DEU	DNK	ESP	FIN	FRA	GBR	GRC	IRL	ITA	NLD	PRT	SWE
Exports from	Austria	(AUT)	0	1054	21587	491	1626	376	2673	2536	267	189	4992	1453	246	714
	Belgium/Lux	(BLX)	1982	0	33075	1596	6198	1028	30982	17007	1039	851	10154	20875	1523	2641
	Germany	(DEU)	27730	28950	0	8869	20952	5143	*57076*	44324	3726	2719	38167	34283	5793	11755
	Denmark	(DNK)	420	734	8137	0	845	1053	1941	3883	326	322	1477	1565	176	4386
	Spain	(ESP)	879	2802	13419	703	0	338	19949	8349	1002	568	9395	3028	9510	1160
	Finland	(FIN)	573	1040	4923	1191	1029	0	2134	3873	428	266	1573	1890	274	3967
	France	(FRA)	3237	21437	*46025*	2557	24502	1467	0	28532	2336	1975	24702	12526	4087	4340
	UK	(GBR)	1900	12868	31248	3355	10678	2179	24757	0	1674	15868	13478	19012	2576	6939
	Greece	(GRC)	120	139	1702	73	227	24	447	647	0	41	999	258	48	126
	Ireland	(IRL)	331	4000	9229	587	1552	251	4868	12949	156	0	1950	3406	238	1092
	Italy	(ITA)	5248	6363	38115	1960	13624	1245	30124	17072	4632	960	0	6685	3351	2514
	Netherlands	(NLD)	2090	16304	33446	2298	4594	1320	14817	14092	1174	936	8209	0	1102	3277
	Portugal	(PRT)	239	1159	4739	371	3566	132	3453	2894	99	113	927	1161	0	475
	Sweden	(SWE)	789	3525	8279	4517	2047	3894	3855	7001	511	573	2865	4532	473	0

Table 5.4 Geographical Pattern of Intra-EU Trade 1998 by Value ($ million)

(Data Source: OECD, 2000)

Finally, Table 5.5 shows the GL index itself for the same data. The index (expressed in % terms) ranges from 10.6 to 99.9. The average value is 75.1%. At an individual country level, Greece typically has the lowest values ranging from 10.6% for trade with Finland to a high of 65.3% with Portugal. The UK has the highest average level of intra-industry trade (85.6%), closely followed by Germany (84.9%), Austria (83.3%), Denmark (80.9%) and Italy (79.8%).

Year 1998		GL														
		AUT	BLX	DEU	DNK	ESP	FIN	FRA	GBR	GRC	IRL	ITA	NLD	PRT	SWE	AVE
Austria	(AUT)		69.4	87.5	92.2	70.2	79.2	90.5	85.7	62	72.7	97.5	82	98.6	95	82.3
Belgium/Lux	(BLX)	69.4		93.3	63	62.3	99.4	81.8	86.1	23.6	35.1	77	87.7	86.4	85.7	72.1
Germany	(DEU)	87.5	93.3		95.7	78.1	97.8	***89.3***	82.7	62.7	45.5	99.9	98.8	90	82.6	85.1
Denmark	(DNK)	92.2	63	95.7		90.8	93.9	86.3	92.7	36.6	70.8	85.9	81	64.4	98.5	79.4
Spain	(ESP)	70.2	62.3	78.1	90.8		49.5	89.8	87.8	36.9	53.6	81.6	79.5	54.5	72.3	69.6
Finland	(FIN)	79.2	99.4	97.8	93.9	49.5		81.5	72	10.6	97.1	88.4	82.2	65	99.1	76.4
France	(FRA)	90.5	81.8	*89.3*	86.3	89.8	81.5		92.9	32.1	57.7	90.1	91.6	91.6	94.1	81.3
UK	(GBR)	85.7	86.1	82.7	92.7	87.8	72	92.9		55.8	89.9	88.2	85.1	94.2	99.6	84.4
Greece	(GRC)	62	23.6	62.7	36.6	36.9	10.6	32.1	55.8		41.6	35.5	36	65.3	39.6	41.6
Ireland	(IRL)	72.7	35.1	45.5	70.8	53.6	97.1	57.7	89.9	41.6		66	43.1	64.4	68.8	61.5
Italy	(ITA)	97.5	77	99.9	85.9	81.6	88.4	90.1	88.2	35.5	66		89.8	43.3	93.5	78.6
Netherlands	(NLD)	82	87.7	98.8	81	79.5	82.2	91.6	85.1	36	43.1	89.8		97.4	83.9	79.5
Portugal	(PRT)	98.6	86.4	90	64.4	54.5	65	91.6	94.2	65.3	64.4	43.3	97.4		99.8	76.3

Table 5.5 The Grubel-Lloyd Index for Aggregate Manufacturing

(Data Source: OECD, 2000)

5.3.2 Explanatory Variables Used in the Econometric Models

The regression models adopted for this chapter relate to the literature and models discussed in section 5.2. The independent variables described can be usefully split into industry characteristics and country characteristics and in one instance a mixture of both.

5.3.2.1 Explanatory Variables at the Industry Level

Market Power

Although as mentioned earlier, some oligopoly models predict a positive relationship between market power and IIT (e.g., Caves 1981), empirical work suggests a strong negative relationship between conventional measures of market power and IIT (e.g., Balassa, 1986c; Aturupane *et al.,* 1999). It follows that it is important to control for market power and that the effect of industrial concentration on intra-industry trade is expected to be negative in the model being formulated. For this study it is important that the measure of market power is created at the EU level and is not the characteristic of any single country. In the context of EU production, Davies and Lyons (1996) have provided estimates of the Herfindhal index of concentration at the three digits level and which depends on both national levels of industrial concentration and the degree of concentration of production among the EU economies. This has been aggregated to the level of 22 sectors using a geometric mean. The identifier used in the reported results is ***heu.***

R & D Intensity

As we have seen, there is no clear empirical prediction for this variable while R&D may contribute to production differentiation, as Greenaway and Milner (1984) for example have pointed out. If R&D activities contribute to the product innovation, firm specific technological know-how about process and/or technical characteristics may be an important potential source of competitive advantage in markets. This is particularly important in international markets for attribute and technically differentiated goods which encompass research intensive countries. Trade by research intensive industries may consist therefore in intra-industry exchange of technologically differentiated goods. Thus R&D has a positive effect on intra-industry trade. On the other hand, if investment in R&D amounts to a relatively large proportion of net output, the barrier to competitive entry and/or incentive to inter-industry specialisation may deter intra-industry exchange. In other words, it will have a negative effect on intra-industry trade. In the empirical analysis, R&D intensity is measured by business expenditure on Research and Development which measured in $PPPs for the EU in each industry deflated by the aggregate level of employment. The identifier is ***eurdpers***.

Product Differentiability

Across industries, the scope for product differentiation varies considerably. Cement for example has few characteristics upon which firms can differentiate their products and this was captured in the theoretical model by allowing for a homogeneous good and a differentiated good. In practice of course industries exist along a spectrum of differentiability, and even basic commodities are differentiable to some extent. As we saw, this has been measured in different ways in the literature. This study is based on the statistical classification system that measures the number of five digits commodities within each industry. The greater the number of sub-headings within each sector, arguably the greater the scope for differentiation. Differentiability is measured by the logarithm of the number of commodity headings at the 5-digits level SITC Rev 3 in each industry. However, this variable may also be capturing the effect of aggregation – the more sub-headings in a sector, the greater the scope that inter-industry trade based upon comparative advantage is masquerading as IIT. The logarithm of the variable is used in the regression analysis reported below and has identifier ***lncomm***.

The Strength of Measurement Infrastructure

One of the key objectives of this study is to consider the role played by the measurement infrastructure in promoting IIT. Here we have specifically described the role of measurement related standards (in chapter 2) and modelled them in chapter 4. Since these are available across the EU level, the study predicts the positive relationship between a count of measurement related standards at the industrial level and IIT. Arguably however, a high standards count for a particular industry may simply reflect the number of different product lines that need to be supported by standards, and indeed, there is a relatively high degree of correlation between the logarithm of the standards count (***lns***) and the logarithm of the number of 5-digit commodities within each industry (***lncomm***). For this reason we use the number of standards normalised by the number of products in each industry as our preferred indicator of the 'public good' effect of measurement standards (identifier ***lsratio***). The dataset of the above mentioned four industry characteristics variables are shown at Appendix 5.1.

5.3.2.2 Industry-Country Characteristics – Market Size

The importance of size is of course a vital element in the monopolistic competition model, captured, as we saw in the last section, in many empirical studies by the use of the average GDP of the two partner countries. As discussed above differences in market size are likely to depress the extent of intra-industry trade. The variables frequently used in the literature are the logarithm of the average GDP for the two economies and the absolute value of the differences in the logs of their respective GDP. These variables are used here (denoted by ***lagdp*** and ***ldiffgdp***). Both are expressed in terms of a common currency using estimates of purchasing power parities (PPPs). However, this study also employs a measure of market size that varies *both* by industry and by country, using the average of the value of production of the two trading partners as the proxy for the market size as well as the difference in market size. Using GDP to capture market size effects does not of course allow for the fact that size also has an industrial dimension. Thus the value of industrial production measured at an industrial level for each of the 22 industries forming our dataset provides a measure of market size. In the results reported here the variable used is logarithms of the average of the value of production of each of the trading partners (***lapi***) and the (absolute value of) the difference in the logarithms of their respective levels of production in each industry (***ldiffpi***). Retaining the GDP measures however allows the estimates to control for other influences possibly correlated with GDP.

5.3.2.3 Explanatory Variables based upon Shared Country Level Characteristics

Level of Economic Development

As explained in section 5.2, intra-industry trade has been related in the literature positively to the level of economic development attained among trading partners, and negatively to the extent of the difference between the two. These are usually measured in terms of GDP (or GNP) per head of population again expressed in a common currency using PPPs. This study follows this approach. The GDP data, along with the population of each country in 1998, was collected from OECD (2002), as shown in Appendix 5.2 (data for Belgium and Luxemburg being aggregated). However it needs to be noted that in the EU context (certainly prior to enlargement) differences in GDP per capita are much smaller than the datasets of other studies of bilateral intra-industry trade which frequently included both developed and less developed economies.

The Distance between Two Countries

Many studies have found the distance between the two trading partners to be an important determinant of intra-industry trade. This is not a particularly clear concept however – what for example is the distance between France and Germany? Data on distance between EU countries are taken from the study by Chen (2002). Most authors have measured distance in terms of the length between the centres of geographical gravity for each pair of countries (as in Balassa and Bauwens (1987)). Alternatively, the distance may also be measured between the economic or commercial centres of country pairs as suggested by Loertscher and Wolter (1980), Bergstrand (1983) and Aitken (1973). While these methods are apparently superior to the approach by measuring the direct air distance between the capitals of two countries, they simply ignore the unbalanced economic development levels across countries. Therefore, the study has employed the approach adopted by Chen (2002). All EU 15 countries are split into 206 regions. The distances between the cities of corresponding regions are measured by the "great circle distance" formula based on the latitudes and longitude of each city. All these distances are weighted by their relative GDP share calculated by GDPm/GDP, where GDPm is the GDP value of a region and GDP is at the whole country level. This method will therefore give more weights to regions with stronger economic activity. The distances between EU countries are given in Appendix 5.3. The logarithm of the distance has been used in all the results reported here (denoted by ***ldist***).

A Common Border

The existence of common borders indicates the possibilities for IIT in response to locational advantages (Grubel and Lloyd, 1975). This relationship has strongly been supported by the study of Balassa and Bauwens (1987). The common border in this study is defined as the trade partners that share land boundaries. The country pairs with a common border are coded as 1, and 0 if not. Clearly such a classification removes the selection of these adjacent countries that are separated by sea, such as UK and France, Sweden and Finland and so on. Finally 12 countries pairs satisfy this definition, as shown in Appendix 5.4. The common border dummy is denoted by ***cb***.

Countries with Common or Similar Language

Language has been regarded as a trade barrier both on inter-industry and intra-industry trade. Countries with common or similar languages will have higher IIT due to the removal of this trade deterrence. Appendix 5.5 lists the common or official languages for each country. The factor of language may be subdivided into several language dummies, with each one related to a particular language such as English, French, Spanish, German, Portuguese, etc., as adopted by Balassa and Bauwens (1987). However, such classifications may make the regression models too complicated and consequently involve in the additional work in data coding and sorting. Therefore, the language factor has been defined as one dummy variable in the model, with 1 coded for country pairs speaking common or similar languages and 0 for others. This results in 4 country pairs coded as 1, Germany and Austria (German), Denmark and Sweden (Scandinavian), France and Belgium/Lux (French), and Belgium/Lux and Netherlands (Dutch). In the results, the language dummy is denoted by ***lang***.

Measurement Infrastructure at the Country Level

In addition to the usual controls for country differences discussed above, there remains the possibility that different economies do not have equal access to the measurement infrastructure. Although the standards counted may be marketed in all the member states of the EU, and the harmonisation of standards has been an important element of policy, their relevance may differ from country to country because of differences in (for example) the availability of services related to measurement. Here, as we have argued, the public goods effect operates at several levels, no simple measure is possible. Our proxy measure for measurement capital in the theoretical model is that of the demand for total consumption of instruments in each economy (i.e., production less exports plus imports). Ideally we would wish to utilise the intensity of instrument use at the industry level. Unfortunately, there is no way of doing this with existing data. However we can use the data we have for the (logarithm of) average intensity of instrument use in each economy pair – ***lacinstratio*** – where intensity is defined as instrument consumption (production less exports plus imports) divided by GDP.

According to the methodology discussed in section 2.5.2, Appendix 5.6 provides the dataset of measurement instrument consumption as well as other input parameters. Figure 5.1 uses a two-axis graph to compare the proportions of measurement instrument consumption to total domestic industry product (PROP_CINST) and the values of total measurement instrument consumption (CINST) across EU countries.

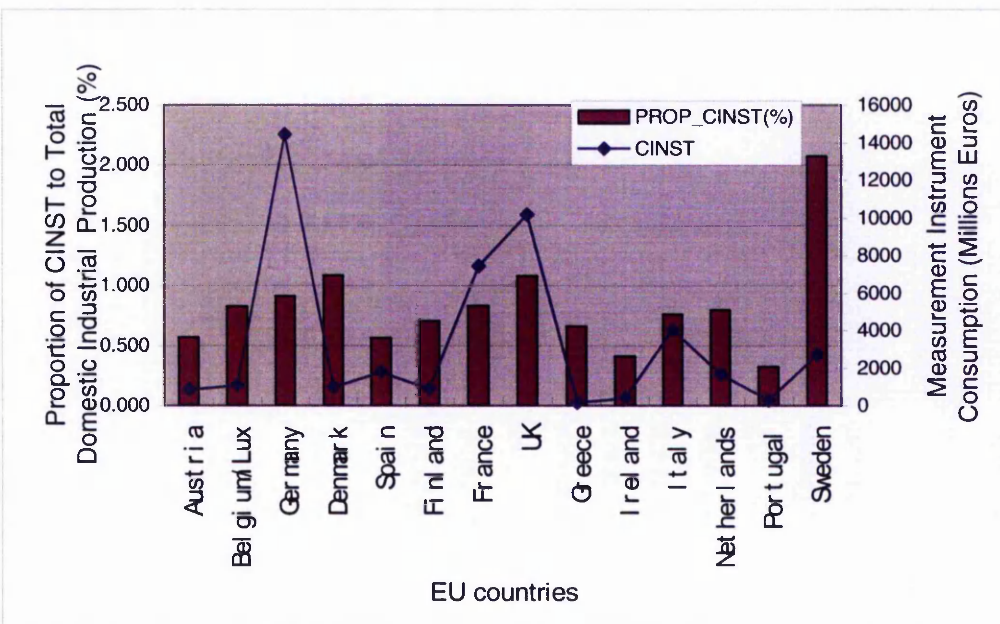

Figure 5.1 Measurement Instrument Consumption in the EU

(Data Source: Spencer and Williams, 2002)

An interesting finding is that although Germany has the highest absolute value of measurement instrument consumption, its relative size (measurement instrument consumption /TDIP) is less than Sweden, which has the highest proportion of 2.071% among 14 countries.

Figure 5.2 compares the proportional PPP GDP and measurement instrument consumption among 14 EU countries. The proportion PPP GDP of a country is defined as the pure value of the country's PPP GDP divided by the sum of all countries, similarly as for the calculation of proportional measurement instrument consumption. It can be seen that two trends are very similar, especially for these 'big' industrial economies. The big difference exists in Sweden, which ranks at 9th by proportional PPP GDP but 5th by proportional measurement instrument consumption. This comparison provides some evidence in support of the assumption that measurement instrument consumption variable may have some similar effects as the determinant of country size measured by GDP on the extent of intra-industry trade.

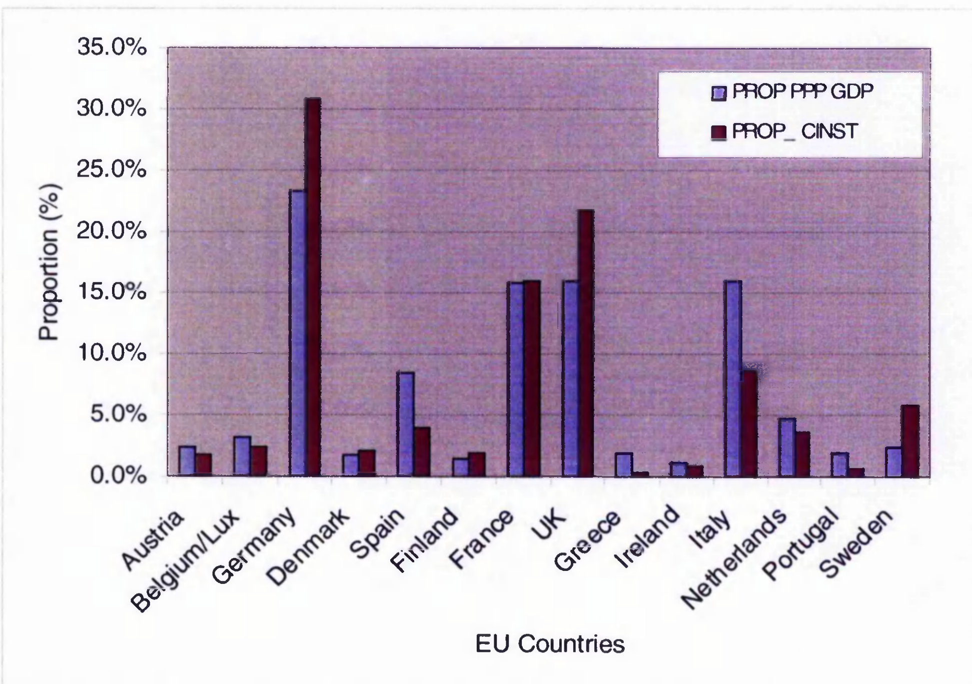

Figure 5.2 Proportional PPP GDP and CINST in the EU

(Data Source: Spencer and Williams, 2002; OECD 2002)

5.4 Regression Analysis

Table 5.6 summarises the earlier discussion of intra-industry trade by listing the independent variables used and showing the predicted signs based upon the various hypotheses examined above, it also shows the sources of data. Column 2 shows the identifiers used.

Variables	Identifier	Description	Impacts on IIT
IIT_{ijk}		Intra-industry trade between country i and j in industry sector k	
Herfindahl index	***heu***	This was constructed from an estimate of the Herfindahl Index at the EU level at the three digits NACE classification[68] and aggregated using a geometric mean of the constituent industries.	-
R&D per person	***eurdpers***	Business expenditure on Research and Development (measured in $ PPPs for the EU (exc Ireland and Portugal) in each industry deflated by the aggregate level of employment	+/-
Product differentiation	***lncomm***	The logarithm of the number of commodity headings at the 5-digit level SITC Rev 3 in each industry	+
Measurement standard intensity	***lsratio***	This is the logarithm of the number of narrow measurement standards normalised by the number of products in each industry as the indicator of the 'public good' effect of measurement standards.	+
Average value of production	***la_pi***	The logarithm of the arithmetic mean of the value of production by industry for each pair of countries in 1998.	+
Inequality value of production	***ldiff_pi***	The logarithm of the difference in the value of production between each pair of countries in 1998.	-
Average per capita GDPs	***la_p_gdpp***	The logarithm of average income per capita for 1998 (measured by GDP/population) between two countries (in Billions).and evaluated in billions of PPP$s as estimated by the OECD	+
Inequality of per capita GDPs	***ldiff_p_gdpp***	The logarithm of the absolute different income per capita between two partner countries (in Billions)	-
Distances	***ldist***	The distance between two trading partners in kilometre. The distances between the cities of corresponding regions are measured by the "great circle distance" formula based on the latitudes and longitude of each city. Therefore, All EU 15 countries are split into 206 regions and all these distances are weighted by their relative GDP share calculated by GDPm/GDP, where GDPm is the GDP value of a region and GDP is at the whole country level.	-
Common border	***cb***	dummy variable = 1 if the country pair share a common border	+
language	***lang***	dummy variable = 1 if the country pair share the same language	+
Average GDP	***la_gdpp***	The logarithm of average GDP values between two countries (in PPP$ billion)	+
Inequality GDP	***ldiff_gdpp***	The logarithm of the difference in GDP between two countries (in PPP$ billion)	-
instrument consumption intensity	***lacinstratio***	The logarithm of average intensity of instrument consumption, where intensity is defined as instrument consumption divided by GDP.	+
ε_{ijk}		Regression disturbance term	

Table 5.6 The Determinants of IIT used in the Regression Analysis

[68] General Industrial Classification of Economic Activities.

Results from a variety of regressions are shown in Table 5.7 below. All the reported results use the ordinary least squares estimator and the dependent variable – the measure of IIT – is the logit transformation of the Grubel-Lloyd Index (IIT) discussed in section 5.2.1 above.

The first two sets of results (1) and (2) attempt to replicate results which have featured in the literature, concentrating on the shared country characteristics determining intra-industry trade, with (for 1) and without (for 2) the use of industry dummies to control for common effects across industries. As mentioned above, the data are for bilateral trade between 13 EU countries and for 22 industries for 1998 providing a maximum of 1716 observations[69]. Result sets 1 and 2 show regressions with and without industry dummies. All standard errors reported use the Huber/White sandwich variance estimator which allows for potential heteroscedasticity. The results are very similar to others reported in the literature. The coefficients on both average GDP and average per capita GDP are positive and highly significant. However while the difference in average GDP is negative and significant – in line with the prediction of the monopolistic competition model - we do not find that the difference in per capita GDP (although negative) has any statistically significant negative impact. This may reflect the fact that these differences are much smaller in a study of the EU (at least prior to enlargement), than in other studies in which per capita income differences are much larger across the sample. The common border variable (***cb***) is signed in line with expectation, but is only significant at the 10% level. The language dummy (***lang***) is however insignificant in all the results. Column 2 shows the same regression but with a full set of industry dummies. While these are jointly highly significant, there is very little change to the coefficients on shared country characteristics, indicating that the cross-sectional variation by industry is operating more or less orthogonally to the shared country characteristics.

As mentioned above, using GDP to capture market size effects does not of course allow for the fact that size also has an industrial dimension. A preferred measure of market size is the value of industrial production measured at an industrial level for each of the 22 industries which form our dataset. Accordingly results set (3) provides results with measures of market size which are the logarithms of the average of the value of production of each of the trading partners (***lapi***) and the difference in the logarithms of their respective levels of production in

[69] Deletes data of Ireland since it lacks value of production by industry.

each industry (***ldiffpi***). Incorporating these new variables shows importantly that although the inclusion of an industry specific measure of market size is important and reduces the impact of the GDP measure of market size, the latter is not eliminated entirely. This suggests that omitted factors, other than simple market size, are correlated with the overall average economic size of the trading partners.

Introducing the industry specific variable representing cross-industry variation in the strength of the measurement infrastructure (***lsratio***) requires the elimination of the set of industry dummies employed in results set (2) and (3) and the incorporation of the other industry variables representing market structure (***heu***), R&D intensity (***eurdpers***), and product heterogeneity (***lncomm***). Results reported in set (4) are those using the 'narrow' standard measure. It can be seen that this variable is positive and significant, indicating that measurement related standards do have an effect on intra-industry trade over and above that provided by market size. The other industrial characteristics used are also significant. The EU degree of concentration has a negative impact on intra-industry trade, while the R&D intensity of the industry (again at the EU level) exerts a positive influence.

In addition to the usual controls for country differences discussed above, there remains the possibility that different economies do not have equal access to the measurement infrastructure. Although the standards counted may be marketed in all the members of EU, and the harmonisation of standards has been an important element of policy, their relevance may differ from country to country because of differences in (for example) the availability of services related to measurement. Here, as has been argued, the public goods effect operates at several levels, no simple measure is possible. Our proxy measure for measurement capital in the theoretical model is that of the demand for total consumption of instruments in each economy (i.e., production less exports plus imports). Ideally the intensity of instrument use at the industry level would be used. Unfortunately, there is no way of doing this with existing data. However data that does exist is for the (logarithm of) average aggregate intensity of instrument in each economy pair - ***lacinstratio.*** The fifth set of results shows that including this variable does have a positive coefficient which is significant at the 5% significance level.

RESULT SET		(1)			(2)			(3)			(4)			(5)		
Dependent variable		*IIT*			*IIT*			*IIT*			*IIT*			*IIT*		
Estimation method		OLS			OLS			OLS			OLS			OLS		
		coefficient	Robust standard errors	sig[a]	coefficient	Robust standard errors	sig[a]	coefficient	Robust standard errors	sig[a]	coefficient	Robust standard errors	sig[a]	coefficient	Robust standard errors	sig[a]
INDEPENDENT VARIABLES	IDENTIFIER															
COUNTRY CHARACTERISTICS																
Log of Average GDP	*la_gdpp*	0.434	0.069	***	0.441	0.068	***	0.310	0.140	**	0.341	0.090	***	0.336	0.090	***
Difference in Log of GDP	*ldiff_gdpp*	-0.110	0.026	***	-0.108	0.025	***	-0.049	0.032		-0.054	0.032	*	-0.057	0.032	*
Log of Average GDP per caput	*la_p_gdpp*	3.581	0.543	***	3.616	0.521	***	3.226	0.548	***	3.435	0.563	***	2.767	0.616	***
Log of Difference in GDP per caput	*ldiff_p_gdpp*	-0.033	0.035		-0.032	0.032		-0.032	0.037		-0.033	0.034		-0.004	0.037	
Log of Distance	*ldist*	-0.467	0.116	***	-0.470	0.110	***	-0.440	0.129	***	-0.507	0.123	***	-0.577	0.121	***
Common Border Dummy	*cb*	0.237	0.131	*	0.233	0.129	*	0.241	0.154		0.247	0.135	*	0.261	0.135	*
Common Language Dummy	*lang*	0.111	0.157		0.117	0.150		0.048	0.199		0.037	0.168		-0.056	0.173	
Log of average intensity of instrument consumption	*la_cinstratio*	-			-			-			-			0.281	0.140	**
INDUSTRY-COUNTRY CHARACTERISTICS																
Log of Industrial production	*la_pi*	-			-			0.343	0.126	***	0.241	0.075	***	0.234	0.076	***
Difference in log of industrial production	*ldiff_pi*	-			-			-0.246	0.050	***	-0.222	0.052	***	-0.216	0.052	***
INDUSTRY CHARACTERISTICS																
Log of number of commodities in industry	*lncomm*	-			-			-			0.323	0.047	***	0.324	0.047	***
EU industry concentration	*heu*	-			-			-			-3.532	1.242	***	-3.661	1.240	***
R&D per person in EU	*eurdpers*	-			-			-			0.027	0.011	**	0.027	0.011	**
Log of standard intensity	*lsratio*	-			-			-			0.291	0.053	***	0.290	0.053	***
Constant		-34.097	5.847	***	-34.097	5.847	***	-32.048	6.081	***	-34.000	6.203	***	-27.427	6.595	***
INDUSTRY DUMMIES		NO			YES			YES			NO			NO		
F-test of industry dummies		-			F(21,1666)=	9.330	***	F(21,1444)=	7.580	***						
No of observations		1695				1695			1475			1412			1412	
F- statistic of equation	F(7,1687) =	44.27		***	F(28,1666) =	19.00	***	F(30,1444) =	17.44	***	F(13, 1398) =	33.08	***	F(14,1397) =	31.31	***
Prob (>F)		0.0000				0.0000			0.0000			0.0000			0.0000	
R^2		0.1588				0.2456			0.2660			0.2363			0.2388	

[a] significance *** variable is significant at 1%; ** 5%; * 10%

Table 5.7 The Determinants of Intra-Industry Trade: Results of Experiments Using OLS Regression

A number of robustness checks were performed on these results and various experiments are reported in Table 5.8. First, as discussed above in section 5.2.1, the literature suggests a number of possible problems with the Grubel-Lloyd measure. The most important was the need for the logistic transformation of the basic measure. However various authors have considered adjustments for the 'overall' trade balance. This function as a 'macro-economic' factor at the country level and the adjusted measures are intended to reflect an overall balance of payments structure which is out of equilibrium. A country with a negative (or positive) overall trade balance for example will bias the Grubel-Lloyd index downward. This suggests that a solution is to simply include a set of country dummies. Results are shown in sets (1). To accommodate this, the shared country characteristics have been dropped. It can be seen that the influence of the industry characteristics are little changed. In particular the impact of standard intensity (***lsratio***) is nearly identical.

RESULT SET	(1)	(2)	(3)	(4)
Dependent variable	IIT	IIT	IIT	IIT
Estimation method	OLS	Hausmann-Wu	Robust Regression	WLS

INDEPENDENT VARIABLES	IDENTIFIER	coefficient	Standard errors	sig	coefficient	Standard errors	sig	coefficient	Standard errors	sig	coefficient	Standard errors	sig
COUNTRY CHARACTERISTICS													
Log of Average GDP	*la_gdpp*				0.355	0.100	***	0.285	0.092	***	0.208	0.073	***
Difference in Log of GDP	*ldiff_gdpp*				-0.058	0.033	*	-0.051	0.032		-0.045	0.025	*
Log of Average GDP per caput	*la_p_gdpp*				2.787	0.632	***	2.145	0.606	***	0.276	0.098	***
Log of Difference in GDP per caput	*ldiff_p_gdpp*				-0.004	0.040		-0.029	0.038		-0.025	0.030	
Log of Distance	*ldist*				-0.573	0.136	***	-0.636	0.131	***	-0.679	0.073	***
Common Border Dummy	*cb*				0.262	0.159		0.170	0.153		0.067	0.116	
Common Language Dummy	*lang*				-0.052	0.209		-0.008	0.201		-0.085	0.158	
Log of average intensity of instrument consumption	*la_cinstratio*	-			0.284	0.131	**	0.294	0.126	**	0.350	0.091	***
COUNTRY DUMMIES		YES			NO			NO			NO		
INDUSTRY-COUNTRY CHARACTERISTICS													
Log of Industrial production	*la_pi*	0.173	0.075	**	0.217	0.078	***	0.278	0.071	***	0.211	0.372	***
Difference in log of industrial production	*ldiff_pi*	-0.179	0.043	***	-0.215	0.050	***	-0.206	0.048	***	-0.159	0.057	***
INDUSTRY CHARACTERISTICS													
Log of number of commodities in industry	*lncomm*	0.333	0.046	***	0.338	0.050	***	0.272	0.044	***	0.206	0.035	***
EU industry concentration	*heu*	-3.727	1.272	***	-3.063	1.580	*	-3.204	1.263	**	-2.761	1.040	***
R&D per person in EU	*eurdpers*	0.027	0.011	*	0.021	0.014		0.025	0.011	**	0.019	0.009	**
Log of standard intensity	*lsratio*	0.289	0.053	***				0.300	0.051	***	0.217	0.041	***
Predicted value of instrumenting equation	*Wuhat*				0.322	0.071	***						
Residual of instrumenting equation	*wu_resid*				0.140	0.226							
Constant		-1.020	1.167		-27.503	6.925	***	-21.398	6.647	***	-3.072[a]	0.372	***
INDUSTRY DUMMIES		NO			NO			NO			NO		
No of observations		1412				1412			1412			1412	
F- statistic of equation	F(18,1936) =	25.84	***		F(15, 1396)=	29.23	***	F(15, 1396)=	31.89	***	F(15, 1397)=	31.89	***
Prob (>F)		0.0000				0.0000			0.0000			0.0000	
R^2		0.2798				0.2390						0.2706	

Note: ***a*** indicates the weight. Variables significant level is the same as Table 5.7

Table 5.8 Robustness Experiments

Second, there is a potential for endogeneity in the standard intensities across industries – it may be that industries with high levels of intra-industry trade generate lots of standards with causation running the other way. Compared to the assumptions of the classical linear regression model, it means that this independent variable is no longer uncorrelated with the error term. To test for this a standard Wu-Hausman test of exogeneity can be applied. This test uses an 'instrumenting regression' of the suspect variable against a set of exogenous regressors. The regression used and reported here employed a lagged value of the logarithm of standard intensity in 1990, (***lsratio90***), as well as the logarithms of the ratio of gross fixed capital formation to gross value added (***lgfx98***) and of the ratio of gross value added to turnover (***lgvaturn98***) for each of the 22 industries. The result of the Wu-Hausman test shows in set (2) of Table 5.8. The coefficient of residual of instrumenting equation is 0.140 which proved that there is no endogeneity problem.

Dependent variable		lsratio		
		coefficient	Standard errors	sig
INDEPENDENT VARIABLES	IDENTIFIER			
Logarithms of the ratio of gross fixed capital formation to gross value added	***lgfx98***	-0.391	0.018	***
Logarithms of the ratio of gross value added to turnover	***lgvaturn98***	-0.256	0.02	***
Lagged value of standard intensity for 1990	***lsratio90***	0.981	0.007	***
Constant		-0.565	0.057	***
No of observations			1716	
F- statistic of equation		F(3,1712) =	7484.59	
Prob (>F)			0.0000	
R^2			0.9292	

Note: variables significant level is same with Table 5.7

Table 5.9 Instrumenting Regression of the lsratio

A further robustness check considered here is the possible problem of heteroscedasticity, where the variance of the error is not constant, violating the constant variance assumptions of the classical regression model. A model – valid from the point of view of the linear regression model - but violating the assumption of a constant variance, will still give unbiased coefficient estimates but Ordinary Least squares will no longer be efficient (Mukherjee *et al.*, 1998) and the usual estimates of the standard errors will not be valid. In fact however, the results shown in Table 5.7 use 'robust' standard errors. Heteroscedastictity is particularly likely to arise in a cross -sectional data-set as employed in the present chapter.

Heteroscedasticity may arise because of some systematic relationship between one of the independent variables and the error, or in a more unpredictable way because of the presence of outliers, which may for example arise in the case of data entry error. Residual plots are sometimes helpful in detecting heteroscedastcity, at least for detecting the presence of outliers. Figure 5.3 is a plot of squared residuals against the predicted values. This figure appears to suggest that there may be some outliers. These outliers have high 'leverage' on the reported coefficients. If for example, they are the result of simple errors in recording the data that could give rise to misleading results. In such circumstances it may be appropriate to use robust regression techniques which weight observations, using lower weights for those which have larger residuals. Results set (3) in Table 5.8 uses STATA®'s robust regression estimator which iteratively establishes a pattern of weights. This estimator begins with the OLS regression using this to calculate the magnitude of the residual using Cook's measure of distance, dropping the observation if the Cooks D-value is greater than one. So-called 'bi-weights' are used to adjust downwards all observations for which the absolute value of the residual is greater than zero. The results using the procedure are reported in set (3). It can be seen that they are very similar to the equivalent results (set 5) in Table 5.7. The coefficients on the two measurement variables are very similar, but the coefficient on the level of instrument consumption in each country is now more precisely estimated.

An alternative source of heteroscedasticity may arise if there is reason to suspect some predictable pattern in the residuals. In this case the pattern can be 'modelled' and the appropriate weights applied. In the case of models of IIT for example, some of the literature suggests that use of the logit transformation may create heteroscedsticity. For example, Bergstrand (1983) suggests that – to avoid heteroscedasticity – the observations be weighted by: $(IIT_{ij}\ (1\ -\ IIT_{ij}))^{1/2}$. Note that when both the dependent and independent variables are weighted in this way, the constant term itself becomes a variable and so no constant terms are employed in the regression. The coefficient on this new variable is however reported under the constant term. Comparing these results (set 4 of Table 5.8) with the OLS result (set 5 of Table 5.7), it can be seen that most variables yield similar results, for example, log of average GDP, log of average GDP per caput are both positive and significant; the differences in the logs of GDP and EU industry concentration are negative and significant using Weighted Least Squares. The common border dummy variable, positive and significant using OLS, becomes positive and insignificant. However, the coefficient on the log of average intensity of instrument consumption variable increased from 0.28 to 0.35 and the significance level increased at the 1% level.

In conclusion, the various robustness checks do not suggest that the econometric results reported above are subject to any substantial problem of misspecification.

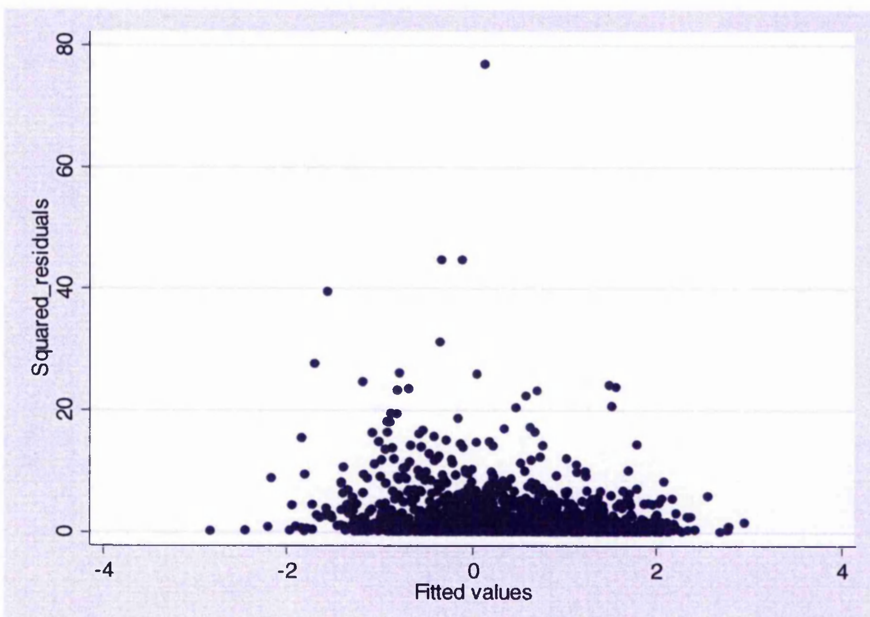

Figure 5.3 Squared Residuals Versus Predicted

5.5 Conclusions

It has been agreed by many economists that a significant portion of international trade is composed of intra-industry trade, which contradicts predictions from the traditional comparative advantage theory. A large amount of econometric literature has been devoted to investigating the causes and determinants of intra-industry trade. With a few exceptions already cited (Swann *et al.,* 1996; Temple and Urga, 1997; Blind and Jungmittag, 2000 in the case of standards more generally), the importance of the impact of national measurement systems on intra-industry trade has been omitted from this literature. However, using controls for other industry and paired-country specific factors suggested by this literature, the analysis here has added additional variables intended to capture the impact on intra-industry trade of measurement infrastructures.

The chapter adopted a cross-sectional regression analysis based on trade flow data across 22 industrial sectors in the EU for 1998 to examine the influence of measurement infrastructure on bilateral intra-industry trade in the EU countries. The variables suggested by the existing literature are common country characteristics, e.g. average GDP per capita, differences in GDP, distance, common language dummies, and common border dummies, as well as industry specific variables providing measures of market power, R&D and product differentiability. The measurement variable at the industry level is provided by a count of measurement related standards (see chapter 2) normalised by the number of commodities listed in the trade classification of an industry. At the country level the intensity of instrument use in relation to GDP was used.

The evidence regarding measurement does not refute the hypothesis that size matters in generating intra-industry trade. Both the average levels of GDP (for each country pair) and absolute differences in GDP are frequently used in the literatures as indicators of the average size of economies and the difference between partners provided statistically significant coefficients throughout. However the interpretation of this in the literature is open to some doubt. In this chapter these measures were supplemented by average values of production (as well as differences) which arguably provide better measures of market size, also provided the expected results, which were highly statistically significant in all experiments. The results of the main experiments reported in Table 5.7 appear to be valid after various robustness checks – reported in Table 5.8 – were carried out.

As far as other determinants of intra-industry trade are concerned, the study supports the relevance of both a common border and distance. However, none of the experiments obtained a statistically significant result for the common language dummy, suggesting that the effect of language variation in the EU is rather weak, possibly because familiarity with English is common, although of course language may still be a significant factor on IIT between the countries where larger distances are involved, such as trade between the countries in the EU and the Asia-Pacific region. This study also provides some evidence in support of hypotheses regarding average per capita GDP, although the study does not find evidence .that differences in per capita GDP are important.

Regarding industry specific variables, industrial concentration has a significant negative effect on the intra-industry trade and. R&D intensity has a positive and significant effect. The industry specific variable intended to capture product heterogeneity was also significant with the expected (positive) sign. Interpretation is open to doubt and probably reflects the aggregation problem as well as product differentiability. However the intensity in which an industry uses measurement related standards was a positive and highly significant influence on intra-industry trade. These results therefore provide further evidence suggesting the importance of measurement infrastructure on the generation of variety. There was also some evidence which suggests that different countries have different access to the measurement infrastructure, reflected in differing intensities of instrument use across the EU which appears to function as an additional determinant of intra-industry trade at the country level. Whether the measurement infrastructure serves as a basis for comparative advantage is considered (for the case of the UK) in the next chapter.

APPENDIX

Appendix 5.1

Dataset of Industry Characteristics Variable for 22 Industries

Industry Number	Industry Describtion	heu (%)	eurdpers ($b)	comm (number)	ms (number)
1	Food, Beverages & Tobacco	0.008	583	101	114
2	Textiles, Apparel & Leather	0.022	4561	122	766
3	Wood Products & Furniture	0.044	2627	19	30
4	Paper, Paper Products & Printing	0.087	13480	6	77
5	Petroleum Refineries & Products	0.057	5151	31	92
6	Chemicals excluding Drugs	0.013	1209	9	22
7	Drugs & Medicines	0.035	9691	67	388
8	Rubber & Plastic Products	0.035	2679	74	735
9	Non-metallic Mineral Products	0.203	9463	27	23
10	Iron & Steel	0.01	2197	365	738
11	Non-Ferrous Metals	0.002	436	128	335
12	Metal Products	0.021	786	6	102
13	Non-Electrical Machinery	0.041	763	184	86
14	Office & Computing Machinery	0.011	569	93	257
15	Electrical Machinery	0.013	922	70	189
16	Radio, TV & Equipment	*	9236	12	187
17	Professional Goods	0.019	17466	5	9
18	Motor Vehicles	0.044	5807	392	623
19	Shipbuilding & Repairing	0.002	232	84	168
20	Other Transport Equipment	0.005	165	38	52
21	Aircraft	0.003	145	356	229
22	Other Manufacturing	0.013	452	282	430

Data Sources: **heu** constructed from Davies and Lyons (1996); **ms** is taken from PERINORM database, based on industry descriptions which were kindly provided by my supervisor. Others are taken from OECD (2004).

Note: Abbreviations for **heu** is Herfindhal index of concentration; **eurdpers** is R&D per person engaged; **comm** is the number of commodity classifications; **ms** is measurement related standards - narrow definition; * is the missing data.

Appendix 5.2

GDP Value and Population in the EU Countries

EU Countries	Population (Millions)	GDP(PPP) ($ Billions)
Austria	8.078	198
Belgium/Lux	10.632	258
Germany	82.029	1944
Denmark	5.303	143
Spain	39.453	711
Finland	5.153	114
France	59.942	1322
UK	59.237	1330
Greece	10.516	158
Ireland	3.705	86
Italy	57.588	1332
Netherlands	15.703	396
Portugal	9.969	162
Sweden	8.851	195

Data Source: OECD (2002)

Note: GDP (PPP): Purchasing power parities converted GDP.

Appendix 5.3

Distance Matrix for the EU Countries

	AUT	BEL/LUX	DEU	DEN	ESP	FIN	FRA	UK	GRC	IRL	ITA	NLD	PRT
AUT	--												
BEL/LUX	807	--											
DEU	549	430	--										
DEN	967	691	560	--									
ESP	1588	1264	1517	1945	--								
FIN	1763	1730	1464	1084	2987	--							
FRA	931	485	724	1128	911	2170	--						
UK	1319	521	869	902	1347	1841	739	--					
GRC	1219	1978	1730	2117	2247	2605	1919	2482	--				
IRL	1703	909	1239	1255	1397	2047	1026	457	2856	--			
ITA	619	1041	909	1432	1293	2247	900	1487	1094	1853	--		
NLD	836	186	400	539	1420	1544	622	536	2023	926	1131	--	
PRT	2061	1570	1900	2297	598	3123	1286	1509	2756	1370	1769	1710	--
SWE	1270	1092	890	427	2315	790	1496	1235	2330	1561	1754	923	2709

Data Source: Chen (2002).

Note: all distance values are in kilometres. Abbreviations for the countries are as follows: AUT, Austria; BEL/LUX, Belgium-Luxemburg; DEU, Germany; DEN, Denmark; ESP, Spain; FIN, Finland; FRA, France; UK, United Kingdom; GRC, Greece; IRL, Ireland; ITA, Italy; NLD, Netherlands; PRT, Portugal; SWE, Sweden.

Appendix 5.4

Matrix of Common Border in the EU

	AUT	BEL/ LUX	DEU	DEN	ESP	FIN	FRA	UK	GRC	IRL	ITA	NLD	PRT
AUT	--												
BEL/LUX		--											
DEU	1	1	--										
DEN			1	--									
ESP					--								
FIN						--							
FRA		1	1		1		--						
UK								--					
GRC									--				
IRL										--			
ITA	1						1				--		
NLD		1	1									--	
PRT					1								--
SWE						1							

Data Source: Calculated by author.

Note: Country pair sharing common land boundary coded as 1. Abbreviations for the countries are as follows: AUT, Austria; BEL/LUX, Belgium-Luxemburg; DEU, Germany; DEN, Denmark; ESP, Spain; FIN, Finland; FRA, France; UK, United Kingdom; GRC, Greece; IRL, Ireland; ITA, Italy; NLD, Netherlands; PRT, Portugal; SWE, Sweden.

Appendix 5.5

Common or Official Language in the EU Countries

	Country	Common or Official Language	Note
1	Austria	German	
2	Bel/Lux	French, Dutch	Dutch is a common language
3	Germany	German	
4	Denmark	Scandinavian	Including Danish and Swedish
5	Spain	Spanish	
6	Finland	Finnish	
7	France	French	
8	UK	English	
9	Greece	Greek	
10	Ireland	English	
11	Italy	Italian	
12	Netherlands	Dutch	
13	Portugal	Portugal	
14	Sweden	Scandinavian	Including Danish and Swedish

Data Source: Calculated by author.

Appendix 5.6

The Calculation of Measurement Instrument Consumption (CINST)

EU Countries	MEU	MNEU	XEU	XNEU	PROD	Total Output (%)	POP	TDIP	CINST	CINST_P	PROP_ CINST (%)
Austria	490	204	229	236	608	0.41	8078	148293	837	104	0.564
Belgium/Lux	675	262	419	122	680	0.52	10632	130769	1076	101	0.823
Germany	1306	2511	3658	3952	18239	1.15	82029	1586000	14446	176	0.911
Denmark	228	118	279	235	1129	1.27	5303	88898	961	181	1.081
Spain	815	282	310	119	1130	0.35	39453	322857	1798	46	0.557
Finland	204	95	154	244	973	0.78	5153	124744	874	170	0.701
France	1532	1531	1565	1168	7114	0.79	59942	900506	7444	124	0.827
UK	1412	2153	1989	2065	10655	1.13	59237	942920	10166	172	1.078
Greece	122	35	8	20	45	0.17	10516	26471	174	17	0.657
Ireland	99	141	110	48	296	0.32	3705	92500	378	102	0.409
Italy	1223	671	700	612	3450	0.65	57588	530769	4032	70	0.76
Netherlands	572	794	939	300	1528	0.73	15703	209315	1655	105	0.791
Portugal	194	57	47	21	109	0.12	9969	90833	292	29	0.321
Sweden	465	317	348	393	2662	2.04	8851	130490	2703	305	2.071

Data Source: Spencer and Williams (2002), Population is taken from OECD (2002);
All numbers are in unit of millions euros, except particularly specified;

Note:

MEU: Imports from the EU countries;
MNEU: Imports from the non-EU countries;
XEU: Exports to the EU countries;
XNEU: Exports to the non-EU countries;
PROD: Demostic Production, which equals to Domestic Sales + Exports
Total Output: Domestic Measurement Production as a percentage of Total Domestic Industrial Production, from OECD (2000a);
POP: Population in 1998 in thousands, from OECD (2002);
TDIP: Total Domestic Industrial Production;
CINST: Total Measurement Consumption;
CINST_P: Total Measurement Instrument Consumption per capita in euro;
PROP_CINST: Proportion of Total Measurement Instrument Consumption to Total Domestic Industrial Production;

Chapter 6

Measurement, Standards and the Pattern of Trade in UK Manufacturing

6.1 Introduction

The previous chapter demonstrated the importance of a measurement infrastructure for the development of product variety and consequently for intra-industry trade in the EU context. This chapter extends the potential impact of measurement on trade by considering the possible impact on specialisation. Specialisation is important for a number of reasons. As was seen in chapter 3 for example, whereas models of intra-industry trade based upon monopolistic competition generate few implications for factor incomes, trade based upon specialisation creates a more mixed, but still relevant picture. When it is based upon relative supplies of factors of production for example, the owners of factors used intensively in import competing sectors may suffer real income losses.

So far measurement technology has been viewed as a support in the development of markets. Technological knowledge, codified in the form of standards, provides an important source of technology for firms. As was seen in chapter 2, many standards relate directly to aspects of measurement. In addition, in the EU context, the harmonization of standards has been one of the fundamental aspects in the creation of the Single European Market. Full access by member states to measurement technology as a result of this harmonization may well have had implications for patterns of trade in both the EU and elsewhere. In particular – given the previous analysis – countries with a large market size may have lost some of the advantages gained from possessing a large national market. The lower prices associated with economies of scale in larger countries may begin to disappear in an integrated market, belonging to the class of goods once described as being of "false" comparative advantage[70]. On the other hand, if the initial strength of the larger economies in these sectors reflects big differences between national firms in terms (for example) of 'tacit' knowledge, then the comparative advantage may persist. This chapter examines some of these issues in the UK context – what evidence is there that the pattern of specialization observed in UK industry is associated with areas related to measurement infrastructure?

As one of the most important contributions of classical economics, the principle of comparative advantage has been named the "deepest and most beautiful result in all economics" [71] predicting both trade specialisation and welfare maximisation. Most mainstream theories of international trade are developed to explain the causes and the consequences of trade arising from comparative advantage. For instance, the Ricardian theory assumes comparative advantage arises from relative productivity differences stemming from natural resources or technological differences, while the Heckscher-Ohlin theory suggests that comparative advantage arises from differences in factor endowments. When these differences are important, countries benefit by specialising according to comparative advantage and exporting what they can produce more economically (at lower opportunity cost) than other countries. In other words, the principle of comparative advantage not only explains the underlying reasons for international trade but also predicts the trade pattern resulting from changes in productivity or factor endowments. The period 1993-2002 is used for the analysis of this chapter during which the creation of the Single European Market may have had a profound impact. In addition, globalization more generally may be important.

The structure of this chapter is as follows. Section 6.2 discusses the determinants of specialisation. Section 6.3 considers how it might best be measured. Section 6.4 describes the

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[70] Refers to Lancaster (1980). Suppose that there are two countries, identical in all respects except size. The country with larger market size has a larger number of manufacturing firms. Because of economies of scale, the relative price and cost of manufactures in the larger country may be lower than small country. This is what Lancaster has called "false" comparative advantage.

[71] Findlay, 1987.

main source of data, providing some initial data analysis. Section 6.5 describes the econometric analysis. Section 6.6 provides a concluding discussion.

6.2 Determinants of Specialization in UK Manufacturing Industries

The earlier review of the empirical literature showed how the 'Leontief Paradox' brought about a substantial amount of both theoretical and empirical work by trade economists in search of alternative or complementary explanations for international trade patterns. In the end, there are perhaps six major groups of explanations that have been widely accepted as accounting for the Leontief results. The consensus that emerged seemed to suggest that the two factor HO model was not an adequate model of the determinants of comparative advantage, necessitating a multi-factor approach which takes both human capital and technology into account. Therefore, this section considers comparative advantage stemming from two factors which draw from the six major explanations groups, namely skilled labour (i.e. human capital), R&D intensity, as well as a country's relative endowments of physical capital and unskilled labour.

Empirical work examining the sources of comparative advantage in international trade for the UK manufacturing industries is relatively small compared with a large number of studies which concentrated on the United States - such as those by Baldwin (1971), and Stern and Maskus (1981). In addition, Balassa (1981) suggests that developed economies export goods that are human and physical capital intensive and import goods that are unskilled labour intensive. This may imply that the UK may possibly show a trade pattern consistent with the Balassa picture, importing goods intensively using unskilled labour and exporting goods intensive in the use of human capital. However, this result cannot be necessarily anticipated: a study carried out by Crafts and Thomas (1986) found that the revealed comparative advantage (RCA) index for the UK – at least before World War II - was positively related to raw labour input intensity and negatively related to human capital input intensity. On the other hand, they did find a positive and significant role for physical capital intensity, using engine capacity installed or in use in each industry (measured in horsepower) as a proxy for the capital stock over the same period. For the post-war period, the empirical work provided by Katrak (1982) suggested the skill-intensity of the UK's imports have increased relative to that of its exports, while the capital-intensities have shown the opposite relative change for the years 1968 to 1978. Furthermore, more recent work by Driffield and Munday (2000) that used the export-import ratio (by log scale) as a measure of comparative advantage, and employing the UK Census of Production data for the years 1984 to 1992, found that the capital labour ratio is negatively associated with industry comparative advantage, indicating a high level of imports in sectors which are capital intensive. This corresponds with results reported by Nachum, Dunning and Jones (1998)[72]. Some of the available evidence is consistent with a weak technological performance on the part of the UK during the last few decades. In her comparative analysis of UK export performance in the 1970s for example, Hughes found that – among other major OECD economies – while the UK and the other major economies had positive relationships between net exports and industrial research intensity, the UK position had weakened and that of Japan had strengthened (Hughes 1986: 163).

The specific hypotheses underlining the regression models reported in this chapter are based upon this existing literature – essentially augmenting a multi-factor Heckscher-Ohlin framework – and are summarised below.

Physical Capital Intensity

According to the Heckscher and Ohlin (HO) theory, factor endowments are regarded as a key explanation of international trade flows. In line with this theory, a country will specialise in the production of goods that can be produced with comparative advantage – those goods which use its relatively abundant factors intensively. In other words, a capital abundant country will have a higher proportion of those goods which use capital more intensively and a labour abundant country will specialise in more labour intensive goods. In this study, physical capital intensity has been obtained by an indirect way (first defined the labour intensity divided by gross value added, then according to Cobb-Douglas equation to calculate the physical capital intensity). As a result, and assuming the UK to be a capital abundant country, the results should show the UK as exporting relatively capital intensive goods while importing relatively labour intensive goods when trading with labour abundant countries.

[72] This study examined the link between the industrial structure of the UK foreign direct investment (FDI) and comparative advantage of the UK, by comparing their dynamic evolution over the last four decades

Human Capital Intensity

The OECD (1998) defined human capital as "the knowledge, qualifications, competences and other qualities possessed by individuals that can be put to productive use". Perhaps the first empirical work, which considered the importance of human capital to trade performance, can be traced back to Leontief. After that, many empirical studies have found that human capital is an independent and significant determinant of comparative advantage, so that a new factor of production - human capital - has been accepted (Crafts and Thomas, 1986; Stern and Maskus, 1981 and Maskus *et al.*, 1994). The most commonly used proxy measures for human capital are those based on educational inputs such as years of schooling or enrolment and administrative, technical and clerical, while some studies have used relative wages (Baldwin, 1971; Dudley and Moenius, 2007 and Crafts and Thomas, 1986). In this study, the relative wage - the wage in a particular industry relative to the manufacturing industry - has been used as an indicator of human capital intensity. This is not perhaps ideal, but under competitive market conditions wages will reflect marginal products which will be higher when skills are higher. For the UK, at least if it is a human-capital abundant economy compared to its trading partners, there is an expectation of a positive effect of human capital intensity on export performance.

Economies of Scale

When average cost falls as the level of production increases, at a relatively large scale of output relative to market size, a country with a larger domestic market can be expected to produce at lower cost. When opened for trade, the country with the larger domestic market will have a comparative advantage in foreign markets. On the contrary, for a small country, the benefits of scale economies can only be reaped from specialisation through trade. Note that cumulative causation may mean that the benefits from a large market persist in some industries, despite increasing integration of national markets within the EU and more generally. There is of course no firm hypothesis in the case of the UK since this will depend upon whether the UK is better able to capture economies of scale than the UK's competitors.

Market Power

Similar to economies of scale, market power is a potentially important determinant of trade patterns but again with no clear prediction as to sign. In general, without competition from abroad, where industries with higher concentration ratios imply that large firms control a high proportion of domestic output, it can make monopolistic or oligopolistic profits. In addition, market power may make strong entry barriers for foreign firms when trade barriers decline. However, these may operate differentially between domestic and foreign producers, encouraging imports [73]. The indicator of market power employed in this study is given by the percentage of total output represented by the top five firms in each industry, i.e. the 'five firm concentration ratio.' This has been adjusted by the extent of import penetration.

Research and Development (R&D) Intensity

An industry's R&D intensity will have direct impact on product innovation and/or process innovation. In general, product innovation reflects a tendency to introduce new products or to differentiate products, providing a main source for intra-industry trade. For the comparative advantage analysis on the other hand, there may be a positive relationship with R&D intensity. Process innovation will increase productivity, according to Ricardian theory; it will magnify countries' comparative advantage at the industry level. In particular, when industry faces competition from international markets, firms may possess specific 'tacit' knowledge about processes and technical characteristics for products. Therefore, it is reasonable to assume that the higher the R&D expenditure, which contributes to both tacit knowledge and indirectly codified knowledge in the form of standards, the stronger the revealed comparative advantage.

[73] However, there is another dispute in the market entry literature as high concentration encourages entry because of the potential for super normal profits, as seen in the empirical work of Rosenbaum and Lamort (1992).

Standards and Measurement Intensity

The primary objective of the chapter is to consider the role played by standards and measurement in determining the UK's pattern of trade. It follows on from earlier empirical work conducted by Swann *et al.* (1996) which first utilised various measures of standards stocks, relating them to UK trade performance. Since the study was conducted for the period 1985-1991, it was conducted when purely 'national' standards were much more important. Nevertheless, the study found that standards – whether of a national or international character – tended to promote not only exports but (more surprisingly at the time) imports as well. This contrasted with a more pessimistic view which argues that standards stock may inhibit trade and competition. However, the 1996 study did find that UK standards – of either type - did have some positive impact on net trade. It will be useful to compare this result with the findings in this chapter.

Other studies have also supported the view that the most important impact of standards on trade is to promote imports. In relation to measurement more particularly, Bowns *et al.* (2003) also suggest that metrology and measurement, which can reduce transactions cost, avoid replication of effort which generally encourages international trade. Moreover, as asserted by Blind (2004), the national system of product and process standards represents a significant element for the innovativeness and competitiveness of a country. In addition, technical standards potentially boost the quality of national products or allow for the realisation of scale economies and in turn make for price competitiveness and trade advantages. Furthermore, the variable of intensity of instrument use has been employed as an additional regressor in later empirical work.

In this chapter, measurement intensity contains two indicators, namely intensity of total standard stock use by industry as well as the intensity of instrument use. These two variables help to explain the impact of measurement infrastructure as discussed in Chapter 2.

Table 6.1 lists the hypotheses of the determinants for this study.

Independent variables	Underlying Theory and Expected Signs Comparative advantage (assumes UK is capital and human capital abundant country)
Physical capital intensity	+
Human capital intensity	+
Unskilled labor intensity	-
Scale economies	-/+
Market power	-/+
R&D intensity	+
Measurement intensity	+

Table 6.1 Hypotheses of the Determinants of Specialisation used in this Study

In summary, this section has discussed the important independent variables. Before moving on to empirical analysis, the next section will introduce the model specification, estimation procedures and data description.

6.3 Measuring Patterns of Trade Specialisation

How should international specialisation be measured? The answer varies since it depends on the precise research objective. However, much of the empirical literature is grounded in the traditional theory of international trade based upon comparative advantage. This theory is based upon differences in relative prices, under situations of autarky (i.e., a self-sufficient economy that eschews international trade). Since these relative prices are unobserved, the empirical literature is based on what can be observed, i.e., patterns of 'revealed' comparative advantage. Ideally perhaps these should be based upon measures of both consumption and production. Perhaps largely for reasons of data availability however, most empirical work has used international trade data (rather than production data) since export and import data are more readily available and should in any event reflect the international specialisation of the country. Perhaps the most frequently used measure of revealed comparative advantage is the Balassa index, which was introduced by Balassa in 1965 and which considers the relative export performance of a country, in particular, its commodities. The index is derived from data on relative export shares and calculated by dividing country $h's$ share in the exports of a given commodity category by the share in the world exports of manufactured goods, as shown in the following equation:

$$RCA_{ih} = \frac{\dfrac{X_{ih}}{\sum_i X_{ih}}}{\dfrac{\sum_h X_{ih}}{\sum_i \sum_h X_{ih}}} \qquad (6.1)$$

Where RCA_{ih} is h country's revealed comparative advantage index for product group i ; x_{ih} are exports of product i by country h , $\sum_i X_{ih}$ are total exports of country h. $\sum_h X_{ih}$ are world exports of product i and $\sum_i \sum_h X_{ih}$ are total world exports. Essentially what this equation does is to normalise the share of any particular product in a country's total exports by the share of that country's for a group of countries total exports.

To interpret, this equation analyses a country's world export share of a product with the country's share of total world exports. If it takes a value of greater than 1, this implies that the country specializes in and has a comparative advantage in the product. Similarly, an RCA index less than 1 indicates that the share of product i in country $h's$ exports is less than the corresponding world share; this implies that the country has a revealed comparative disadvantage in the product.

There are several well known problems with the Balassa index. First, as noted by Proudman and Redding (2000), its mean value does not equal 1. A country for example with high export shares in a small number of products may have a mean Balassa index below 1. Consequently they propose normalising the export share by the mean export share across the categories.

Second, some trade economists have argued that the main problem with the Balassa index (at least if used in econometric estimation) is that its index value is asymmetric. It varies from one to infinity for products in which a country has a revealed comparative advantage, but only from zero to one for commodities with a comparative disadvantage. This asymmetry creates a problem in that the mean of the index is higher than its median, so that the distribution of the index will be skewed to the right, meaning that the relative weight of sectors will be overstated compared to sectors which are less than unity. This is a problem for econometric analysis (e.g. De Benedictis and Tamberi, 2001) since the assumption of normality is violated. Various alternative formulae for measuring the revealed comparative advantage index have therefore been proposed providing symmetry (including Kunimoto (1977), Hillman (1980), Bowen (1983), Yeats (1985), and Vollrath (1991)), creating a long-running controversy. A typical response to the problem has been to use a simple logarithmic transformation of RCA, although this has the problem of zero values and that a change in RCA from say 0.01 to 0.02 is shown as a change from 50 to 100. An alternative example of a simple symmetric alternative is provided by an index such as that suggested by Laursen (1998) who proposes the simple transformation of *RCA: (RCA-1)/ (RCA+1)*. This avoids the problems of both asymmetry and zero values.

However, in the main, and surprisingly given the extent of empirical literature, the controversy has not centred on the important fact that solely export based measures do not consider imports. Given the subject of the current thesis, the role of intra-industry trade is hard to ignore. Various measures which incorporate imports have in fact been proposed in the literature, such as the Michaely index (Michaely, 1962).

The Michaely index is defined as:

$$MI_{ih} = \frac{X_{ih}}{\sum_i X_{ih}} - \frac{M_{ih}}{\sum_i M_{ih}} \qquad (6.2)$$

where X_{ih} and M_{ih} are exports of sector *i* from country *h* and imports for sector *i* to country *h*, respectively. The first term of the right hand side of equation (6.2) represents the percentage share of a given sector in national exports, while the second term of equation (6.2) represents the percentage share of a given sector in national imports. The measure ranges between (-1; 1), with a neutral value of zero providing a measure of 'dissimilarity'; positive values indicate that a country is specialised in an industry or sector, a zero value that it is similar to the overall trading pattern (Laursen, 1998). It has been used as a specialisation index by later studies such as Kol and Mennes, 1985; Webster and Gilroy, 1995 and Bender and Li, 2002.

Given the aims of this thesis, it is of course important to consider net trade, but analysing both together may result in the loss of important information. On the other hand, an advantage of an index such as the Michaely index is the elimination of re-exports as a source of distortion (Laursen 1998). However, if our interest is in the impact of measurement and standards, where our expectation, given the theoretical analysis of chapter 4 as well as the empirical analysis of chapter 5, is for a positive impact on *both* exports and imports, then it will be useful to confirm this by examining exports and imports separately, with the overall impact on net trade being the difference between the two.

Examining exports and imports separately however, raises the question of normalisation allowing for comparison between industries which do not depend upon industry size. Since the value of exports and imports are measured gross of intermediate inputs, the appropriate normalisation is industry sales, i.e. (gross) output rather than value added. The data source is now considered in the next section, together with some preliminary analysis of the data.

6.4 Data Analysis

The data used for the investigation of chapter 6 uses data for the same set of industries analysed in chapter 2 and for which data were created for both stocks of relevant standards made available from the BSI and through the 'supply-use tables' for the UK in the use of instruments. The supply use tables themselves contain information on the supply of and demand for industrial output across 123 industries. The classification is not consistent with any single level of the Standard Industrial classification, but approximates roughly to the 3-digit level. The focus here is on the 77 industries constituting the manufacturing sector of the economy. These are listed in the Appendix to this chapter. Combining the supply-use data with the standards data allowed for 10 years of data – 1993 to 2002.

Each row of the supply-use tables contains data on the demand for the 123 products – the 123 intermediate demands stemming from the 123 industries, as well as data on final demands for the products. Of these, the final export demand exports are broken down into the export of goods and the export of services. Of the 77 industries constituting manufacturing in these data, 2 process industries – by definition - do not export any goods. These are textile finishing (SIC 17.3) and metal casting (SIC 28.4 and 28.5). In addition, the count of standards was not able to distinguish between different types of building materials. As a result, three industries in the original supply-use tables were combined for this chapter (SIC 26.4 to SIC 26.8). The result is therefore a dataset constituting a panel of 73 industries over a 10 year period. Imports constitute an additional source of supply for the 123 products. Both export and import data are broken down into EU and non-EU destinations/sources.

As discussed in section 6.3, the main variables of interest are the exports and imports normalised by the sales (output) industrial of each industry. At the level of aggregate manufacturing, it can be seen from Figure 6.1 that the UK runs a deficit on its trade in manufactured goods: this was about 5% of industrial output in the early part of the period before widening considerably after 2000. The tradability of manufacturing output also increased over the period, with both ratios showing increases over the period.

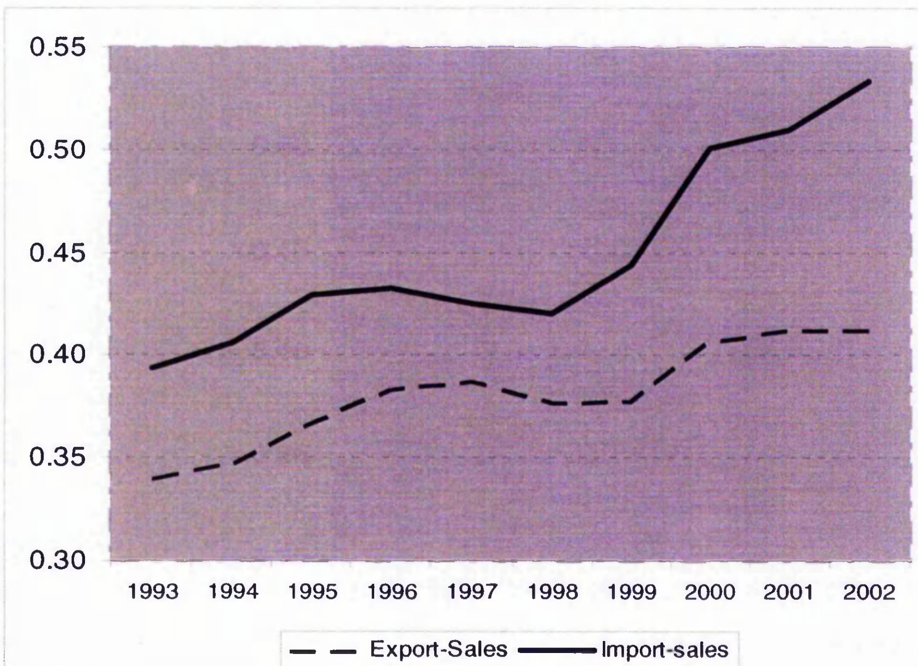

Figure 6.1 Export-Sales and Import Sales Ratios in UK Manufacturing

As far as the direction of trade is concerned, Figure 6.2 shows that the share of UK manufacturing trade with the EU as either a source or destination has remained fairly stable over the period. The period includes the enlargement of the EU to 25 members (now 27). The enlargement is reflected in the trade data from 1998 onward, i.e., it is for the EU25. Prior to that the data are for the EU15. Despite the trend toward globalization, the strengthening degree of purely European integration has meant that the EU remains the biggest source of UK imports and destination for UK exports of manufactured goods.

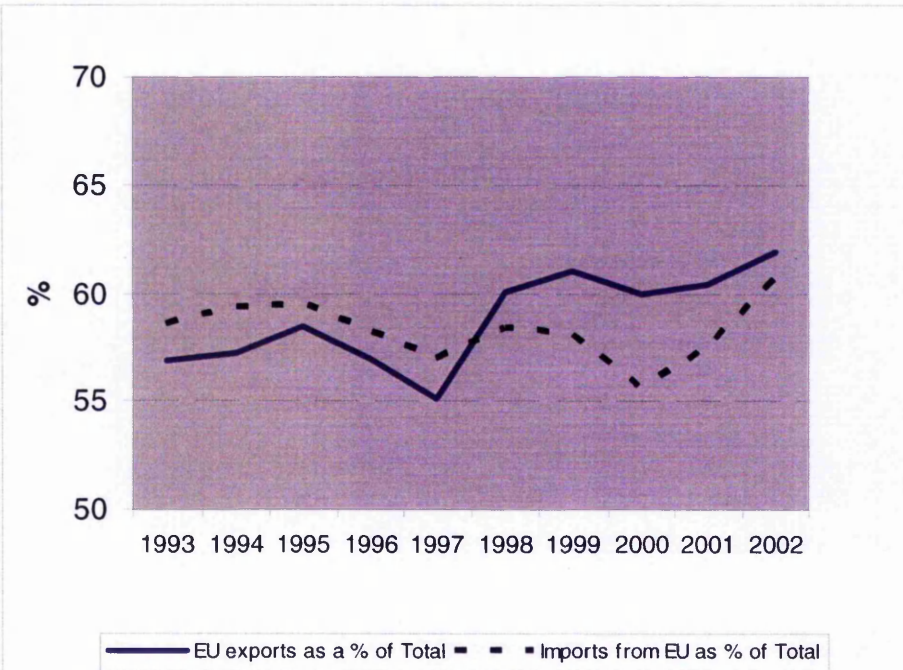

Figure 6.2 The EU as UK partner in Manufactured Goods Trade

A degree of persistence in the pattern of specialisation is of course important if the underlying pattern of trade reflects long-run features. Previous research on this point in the case of the UK has been conducted by Proudman and Redding (2000) who investigated the pattern of specialisation for UK manufacturing as well as other major economies – at a rather higher level of disaggregation - over the period 1970-1993. They note that the question of persistence is an empirical one, since the long run factors which may determine a particular pattern in the trade literature (technology and sector specific learning by doing, factor supplies) may be undermined by forces for mobility (e.g. technology spillovers). Similar to other major economies (US, France, Germany) they find that there is no long run pattern of increasing specialisation in the UK. Japan presents a possible exception.

Figures 6.3 and Table 6.2 illustrate the extent of persistence for the export-sales ratio. Figure 6.3 is a scatter plot comparing the export-sales ratio in 2002 with that of 1993. Many of the industries have increased their export-sales ratio over this period, as indicated by the fact that most of the industries lie above the 45° line. Three industries lay outside the main scatter. One industry – producing transmitters for TV, radio and phone – has seen an enormous increase in the export-sales ratio which may be connected with the export of mobile phone equipment. The others, electronic components and jewellery, with export-sales ratio apparently in excess of one, may represent products with substantial re-exports (goods imported and exported without domestic processing).

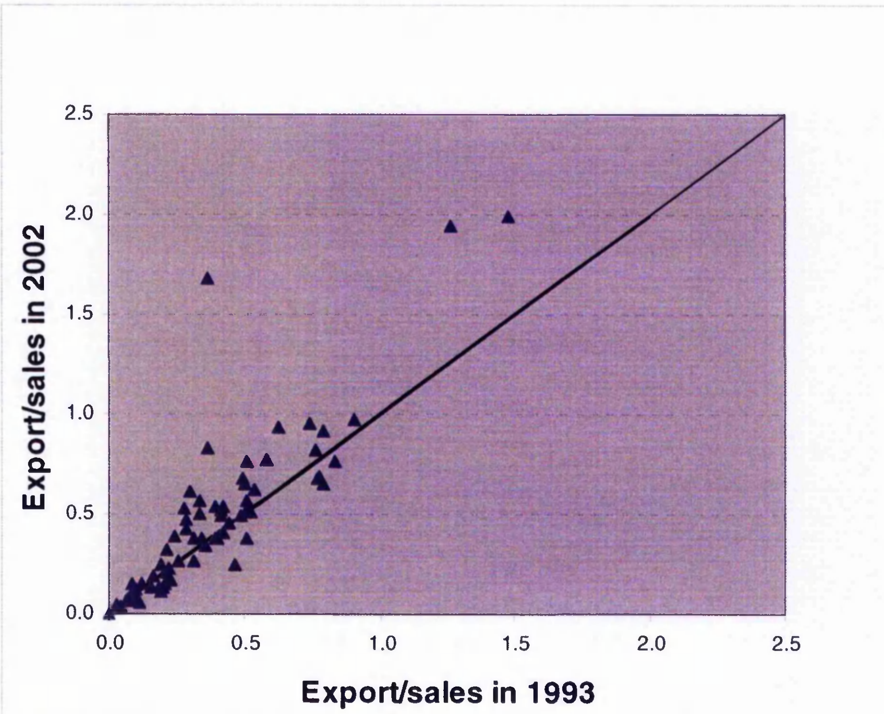

Figure 6.3 Export-Sales Ratio in 1993 and 2002

Table 6.2 shows simple correlation coefficients between the different years in the sample. Even by the end of the period (2002), there is still a strong correlation (0.868) between the export sales ratio in 2002 and that of 1993.

	xs1993	xs1994	xs1995	xs1996	xs1997	xs1998	xs1999	xs2000	xs2000	xs2002
xs1993	1.000									
xs1994	0.973	1.000								
xs1995	0.981	0.979	1.000							
xs1996	0.972	0.973	0.993	1.000						
xs1997	0.927	0.952	0.958	0.974	1.000					
xs1998	0.935	0.957	0.964	0.978	0.990	1.000				
xs1999	0.940	0.942	0.964	0.980	0.971	0.978	1.000			
xs2000	0.944	0.925	0.965	0.969	0.927	0.936	0.977	1.000		
xs2002	0.868	0.888	0.918	0.927	0.903	0.920	0.924	0.930	0.930	1.000

Table 6.2 Simple correlation coefficients between export-sales ratios 1993-2002

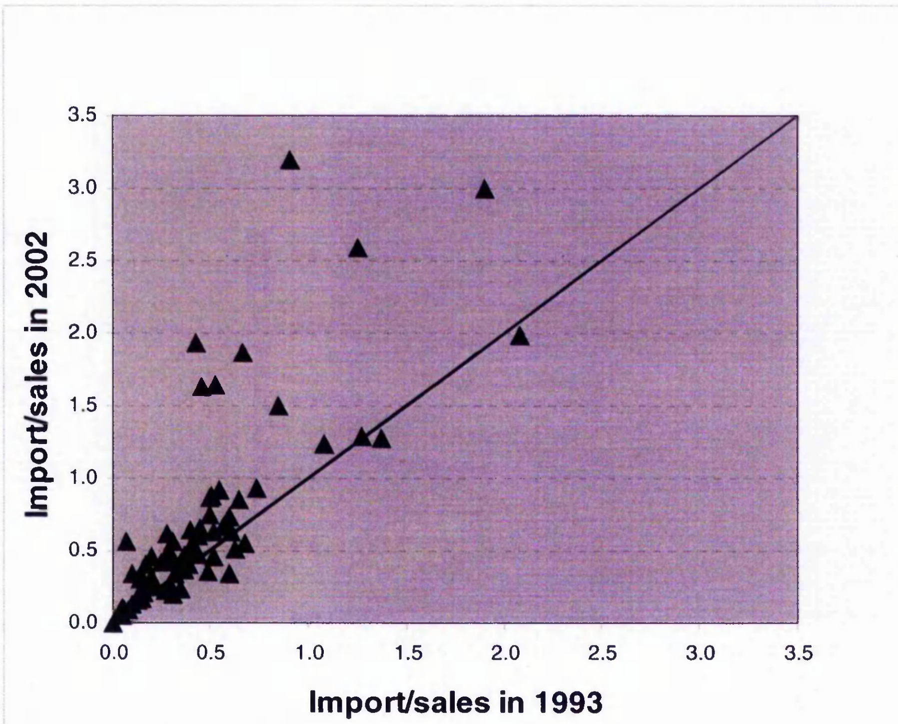

Figure 6.4 Import-Sales Ratios in 1993 and 2002

Figures 6.4 and Table 6.3 illustrate the extent of persistence of the import-sales ratio. Figure 6.2 is a scatter plot comparing the import-sales ratio in 2002 with 1993. As with export-sales many of the industries have increased their import-sales ratios over this period. Meanwhile, there are three industries lay over 2.5 in year 2002. One such industry is footwear which increased from 0.91 increased to 3.2. The others, as before, are electronic components and jewellery, with import-sales ratio which rise from 1.3 to 2.6 and 1.9 to 3.0 respectively. In addition, there are strong correlations of import-sales ratio between the ten years as shown in Table 6.3.

	ms1993	ms1994	ms1995	ms1996	ms1997	ms1998	ms1999	ms2000	ms2001	ms2002
ms1993	1.000									
ms1994	0.998	1.000								
ms1995	0.993	0.995	1.000							
ms1996	0.990	0.993	0.995	1.000						
ms1997	0.989	0.993	0.986	0.994	1.000					
ms1998	0.986	0.989	0.980	0.987	0.998	1.000				
ms1999	0.978	0.981	0.974	0.984	0.994	0.996	1.000			
ms2000	0.954	0.956	0.955	0.969	0.974	0.975	0.986	1.000		
ms2001	0.949	0.954	0.948	0.970	0.978	0.976	0.985	0.989	1.000	
ms2002	0.930	0.938	0.930	0.955	0.966	0.964	0.975	0.971	0.995	1.000

Table 6.3 Simple correlation coefficients between import-sales ratios 1993-2002

The advantages of having a more disaggregated data consists must be set against a variety of limitations imposed by the data-source. At least some of the variables suggested as determinants of specialisation in the previous section are not directly available at this level of aggregation. In particular, direct measures of capital and human capital are not available, and nor are R&D expenditures. Measures of concentration are however available from the ONS at the same level of aggregation as the supply-use tables, if only for 2004.

As far as physical capital is concerned however, some use can be made of the data available in the supply-use tables, since information is available on both labour compensation and value added, and hence on the share of both labour (and therefore capital) in value added. Under the special circumstance that production functions in manufacturing are 'Cobb-Douglas' in nature, variation in the share of capital across industries can be used as an indicator of the capital intensity of production. This can be seen as follows:

The Cobb-Douglas production function relating outputs to inputs is given by

$$Y = F(K, L) = AK^{\alpha}L^{1-\alpha} \tag{6.3}$$

where Y is the total output, K and L indicate capital and labour input, respectively. A indicates technology which is assumed to be 1. α and $1-\alpha$ are the output elasticities of capital and labour respectively, and α is some number between 0 and 1.

Firms in the economy pay workers a wage, w, for each unit of labour, and pay r in order to rent a unit of capital for one period. Assuming the price of output in the economy to be unity, profit-maximizing firms solve the following problem:

$$\max_{K,L} F(K,L) - rK - wL \quad (6.4)$$

According to the first order conditions for this problem, firms will employ labour until the marginal product of labour is equal to the wage and will rent capital until the marginal product of capital is equal to the rental price:

$$w = \frac{\partial F}{\partial L} = (1-\alpha)\frac{Y}{L} \quad (6.5)$$

$$r = \frac{\partial F}{\partial K} = \alpha\frac{Y}{K} \quad (6.6)$$

Then the wage-rental ratio is:

$$\frac{w}{r} = \frac{1-\alpha}{\alpha}\frac{K}{L} \quad (6.7)$$

Rearranging equation (6.7) and using the natural logarithm, the following expression is obtained

$$\ln\frac{K}{L} = \ln\frac{w}{r} + \ln\frac{\alpha}{1-\alpha} \quad (6.8)$$

Equation (6.8) implies that the labour share difference may be because of two important factors, the capital labour ratio and the wage-rental price of capital ratio. Under competitive conditions, *ln(w/r)* will be equal across industries, so that an indicator of capital intensity can be obtained by the logistic of the capital share, i.e., $ln\ (\alpha/(1-\alpha))$.

In a model with human capital of course, the capital share will also reflect higher marginal products of more skilled labour, and in competitive conditions the wage of workers. Although there are no data in the Supply-Use Tables on wages, it is possible to obtain data on labour compensation per unit of labour at a slightly lower level of aggregation from the Annual Business Inquiry (ABI) database. The data has rather a large number of missing observations and is only available for 1995-2002, but it proved possible to compute for nearly all industries an average for the ratio of total employment costs in £million to the total employment at average during the year relative to that in manufacturing in general. This is discussed further below.

Perhaps the other major limitation of the data is the absence of R&D data at the level of aggregation in the Supply-Use Tables. Having had an initial look at the data, the chapter now considers econometric analysis.

6.5 Econometric Analysis

This section considers the determinants of the pattern of specialisation in UK trade, considering both exports and imports separately before briefly turning to net trade. The analysis requires that a long-run pattern of imports and exports is established. In this regard, it is helpful first of all to consider the panel nature of the data.

The data discussed above forms a panel data set. There are several benefits from using panel data, as Klevmarken (1989) and Hsiao (2003) have suggested, i.e., that compared with time-series and cross-section datasets, panel data are better able to control for heterogeneity across individuals, firms, states or countries. This allows researchers using panel data models to construct and test more complicated behavioural models than purely cross-section or time-series data. Furthermore, according to Greene (2002) for example, employing panel data analysis will increase precision of estimates due to the increased sample size, making feasible controls for immeasurable individual specific fixed effects and so on.

Although the dataset used forms a panel, the main purpose of the econometric analysis is to understand the long run pattern of trade specialisation and its determinants. In fact, many of the movements in both export-sales and import-sales ratios are short term in nature. Short term influences include (for example) cyclical factors operating at the macro-level and movements in the exchange rate. The first task is to therefore to extract from the available data the long-run cross industry pattern of trade. In order to consider this further, it is useful to consider the main estimation methods using panel data.

In order to investigate the different impacts of measurement on UK trade performance in the period 1993 to 2002, export-sales ratios and import-sales ratios are estimated separately. The data used forms a panel data set, i.e., with both industry and time dimensions. The panel data model can be written as:

$$y_{it} = x_{it}\beta + u_{it}, i = 1,...,n \; ; \; t = 1,...,T \tag{6.9}$$

where y_{it} is the observation on the dependent variable y for the ith industry in the tth period, x_{it} is a $1 \times k$ vector of observations on k explanatory variables for the ith industry in the tth period, and β is a $1 \times k$ vector of parameters.

u_{it} is a disturbance term and assume that

$$u_{it} = \alpha_i + v_{it} \tag{6.10}$$

Equation (6.10) is defined as the combined error term, therefore, the error term contains an unobservable individual specific effect α_i and a remainder disturbance v_{it}. α_i captures characteristics of the industry i which are assumed to be time invariant. It is precisely the pattern of these time invariant effects that we wish to estimate in this section.

There are two principal methods of analysing the panel data according to different assumptions about the individual specific effects α_i: the fixed effects model and the random effects model.

The fixed effects model assumes that the individual specific effects can be thought of as a set of constants α_i which vary from group to group, in this case from industry to industry. Substituting equation (6.10) in equation (6.9) gives:

$$y_{it} = x_{it}\beta + \alpha_i + v_{it} \tag{6.11}$$

Here the α_i are constant over time. Equation (6.11) can be averaged over the T periods to obtain the single cross section equation:

$$\bar{y}_i = \bar{x}_i \beta + \alpha_i + \bar{v}_i \qquad (6.12)$$

where $\bar{y}_i = T^{-1}\sum_{t=1}^{T} y_{it}$, $\bar{x}_i = T^{-1}\sum_{t=1}^{T} x_{it}$ and $\bar{v}_i = T^{-1}\sum_{t=1}^{T} v_{it}$.

In fact (6.12) can be used to obtain estimates of the fixed effects and is known as the 'between' estimator. Because α_i is fixed over time, it appears in both equations (6.11) and (6.12). Subtracting equation (6.12) from equation (6.11),

$$\ddot{y}_{it} = \ddot{x}_{it} \beta + \ddot{v}_{it}, \; t = 1,\ldots,T \qquad (6.13)$$

where $\ddot{y}_{it} = y_{it} - \bar{y}_i$, $\ddot{x}_{it} = x_{it} - \bar{x}_i$, and $\ddot{v}_{it} = v_{it} - \bar{v}_i$. By differencing, the individual specific effects α_i have been removed. This suggests that we can estimate equation (6.13) by the fixed effects estimator. This is sometimes called the 'within-groups' estimator, because it looks at how changes in the explanatory variables cause y to vary around mean within each industry. It is also sometimes called the least squares dummy variable (LSDV) model because it is equivalent to allocating a dummy variable for each industry.

By contrast with the fixed effects model, the random effects model assumes that the individual specific effects α_i are drawn from some specified distribution, independent of the error term v_{it} and also mutually independent of and uncorrelated with any explanatory variables. While this is a disadvantage, it also allows more degrees of freedom. The assumption allows the α_i to be left in the error term.

Begin with the same unobserved effect model as before,

$$y_{it} = \beta_0 + x_{it1}\beta_1 + \ldots + x_{itk}\beta_k + \alpha_i + v_{it} \qquad (6.14)$$

Since the combined error term $u_{it} = \alpha_i + v_{it}$, the equation (6.14) can be written as

$$y_{it} = \beta_0 + x_{it1}\beta_1 + \ldots + x_{itk}\beta_k + u_{it} \qquad (6.15)$$

Both formal tests and reasoning can be used to decide between fixed and random effects. In practice if there is uncertainty about whether the effects may be correlated with the regressors, then the fixed effects model may be a safer choice (see Mundlak, 1978). A test for the validity of the assumption of orthogonality of regressors and errors has been developed by Hausman (1978). The details of the Hausman test as it is carried out in the current context can be found in the Appendix to this chapter. However, in the current context, in which the population of manufacturing industries is represented, we are interested in the correlation between the explanatory variables and the fixed effects. In fact the Hausman test also supports the choice of the fixed effects estimator.

The above discussion suggests that the within estimator can be used to obtain estimates of the fixed effects. If we assume that short-run influences on the pattern of trade specialisation reflect macro-economic influences – both domestic demand and foreign demand and the exchange rate - then these may be picked up by assuming that these act in a similar way across industries, so that we can augment the 73 fixed effects by a set of time dummies. A further modification allows for first order serial correlation among the residuals. The estimated model is therefore:

$$y_{it} = \alpha_i + \delta_i td + u_{it} \tag{6.16}$$

where i=1,...N; t=1,...,t. N and t are the numbers of the industries and time periods included in the data sample respectively; the *td* are time dummy variables. In principle, α_i captures the 'permanent' long run pattern of comparative advantage, the pattern of $\delta_i td$ captures any systematic trend in this pattern; the error term is u_{it}.

Results of the estimation of the fixed effects model are provided in Table 6.4 for both export-sales and import-sales. Results from estimating equation 6.16 are shown with and without the adjustment for first order autocorrelation of the residual terms. The extent of the autocorrelation can be judged by a 'modified' Durbin Watson statistic. This is based upon the work of Bhargava *et al.* (1982). The estimates in Table 6.4 allow for the fixed effects to be established, i.e., the long-run pattern of exports and imports.

Table 6.5 displays results from the second stage of the analysis – cross-section regressions based upon the long–run pattern of import- and export-sales ratios. The table shows a number of experiments. In each case the dependent variable has been obtained from the fixed effects estimated from results set 2 in Table 6.4. The main independent variable of interest in the results is the 'intensity' of standard use by industry, which is the logarithm of the *total* stock of standards In experiments this typically provided a greater degree of explanatory power then the measure which focused only upon 'measurement related' standards (as described and explained in chapter 2). The intensity of standards use in each industry has been measured by normalising the standard stock on industrial output. The identifier in the table is ***lsio*** and it has been found by averaging the logarithm of the intensity of standards use between industries over time.

Result set 1 shows the result when the other control/explanatory variables are simply the logistic transformation of the 'capital-share' in value added (as explained in the last section and identified by ***lcapshare***) and the extent of industrial concentration. As with standards, the latter is based upon the 5 firm domestic concentration ratio based upon output, i.e., the proportion of output accounted for by the largest 5 firms. It has been modified to include the impact of imports on competition, so that the crude ratio has been multiplied by *(1-m)* where *m* is the ratio of imports to total sales. It is identified in the table by ***c5_om***.

Result set 1 suggests that of the three variables, only the intensity of standard use – ***lsio*** - is both correctly signed (positive) and statistically significant at conventional levels. The sign on the logistic transformation of the capital share is correctly signed but significant at only approximately 15%. This may reflect the fact that the UK is not especially capital abundant compared with its trading partners, but quite possibly may be a result of the fact that the labour share of an industry reflects not just the ratio of physical capital to 'homogeneous' labour but also differences in human capital across industries. To try and capture this effect an indicator of the wage in any particular industry *relative* to that for manufacturing as a whole has been included in the second result set (the variable is in logs and identified by ***relwage***). The addition has important consequences. Not only is the additional variable positively and significant at the 1% level, but the coefficient on ***c5_om*** – adjusted industrial

RESULTS OF FIRST STAGE ESTIMATION

Result Set	(1)			(2)			(3)			(4)		
Dependent Variable	Log of Export-Sales ratio			Log of Export-Sales ratio			Log of Import-Sales ratio			Log of Import-Sales ratio		
Estimation Method	Fixed Effects Estimation			Fixed Effects Estimation			Fixed Effects Estimation			Fixed Effects Estimation		
AR1 correction	NO			YES			NO			YES		
	Coefficient	t-ratio	Sig	Coefficient	t-ratio	Sig	Coefficient	t-ratio	Sig	Coefficient	t-ratio	Sig
1993 Dummy	-0.112	-4.44	***				-0.361	-11.60	***			
1994 Dummy	-0.067	-2.66	***	0.007	0.51		-0.341	-10.96	***	-0.080	-5.20	***
1995 Dummy	-0.024	-0.94		0.026	1.37		-0.285	-9.15	***	-0.098	-4.90	***
1996 Dummy	0.020	0.78		0.052	2.50	**	-0.242	-7.78	***	-0.110	-4.94	***
1997 Dummy	0.018	0.73		0.039	1.80	*	-0.255	-8.20	***	-0.164	-7.02	***
1998 Dummy	-0.005	-0.19		0.008	0.38		-0.226	-7.27	***	-0.165	-7.08	***
1999 Dummy	-0.028	-1.13		-0.021	-1.00		-0.169	-5.43	***	-0.131	-5.86	***
2000 Dummy	0.001	0.05		0.005	0.28		-0.088	-2.84	***	-0.067	-3.34	***
2001 Dummy	0.003	0.14		0.005	0.35		-0.047	-1.50		-0.038	-2.45	***
constant	-1.159	-65.10	***	-1.155	-189.19	***	-0.766	-34.82	***	-0.739	-123.67	***
F-test of time dummies	F(9,639)	5.4	***	F(8,568)	2.01	**	F(9,639)	31.06	***	F(8, 568)	8.57	***
Modified Durbin Watson				0.683						0.514		
Rho (AR)				0.676						0.743		
No of observations	720			648			720			648		

*** sig at 1% ** 5% * 10%

Table 6.4 Results of Fixed Effects Estimation

REGRESSIONS OF EXPORT-SALES RATIOS

Result Set		(1)		(2)		(3)		(4)		(5)	
Dependent Variable		Log of Export-Sales ratio		Log of Export-Sales ratio		Log of Export-Sales ratio		Log of Export-Sales ratio		Log of Export-Sales ratio	
Estimation Method		OLS		OLS		Robust Regression		OLS		OLS	
Explanatory Variable	Identifier	coefficient	t-ratio Sig	coefficient	t-ratio Sig	coefficient	t-ratio Sig	coefficient	t-ratio Sig	coefficient	t-ratio Sig
Logistic of capital share	*lcapshare*	0.308	1.48	0.178	0.87	0.166	0.78	0.309	1.34	0.238	1.13
Intensity of standards use	*lsio*	0.275	3.55 ***	0.242	3.23 ***	0.240	3.08 ***	0.176	2.04 **	0.219	2.83 ***
Adjusted industrial concentration	*c5_om*	-0.006	-1.11	-0.016	-2.49 **	-0.016	-2.52 **	-0.015	-2.20 **	-0.015	-2.39 **
Relative wage	*relwage*			1.008	2.98 ***	1.092	3.11 ***	0.585	1.48	0.847	2.32 **
Intensity of instrument use	*linstio*									0.089	1.14
Sector dummy (SIC20-22;36-37)	*dum1*							-0.385	-1.15		
Sector dummy (SIC 23-25)	*dum2*							0.365	1.21		
Sector dummy (SIC 26-27)	*dum3*							-0.004	-0.01		
Sector dummy (SIC 28-29)	*dum4*							0.171	0.55		
Sector dummy (SIC30-33)	*dum5*							0.561	1.50		
Sector dummy (SIC34-35)	*dum6*							0.470	1.07		
Constant		1.337	3.68 ***	0.305	0.63	0.247	0.49	0.463	0.82	0.962	1.28
F-test of Sector Dummies								F(6,59) =	1.12		
No of obs		72		70		70		70		70	
F-test of equation		F(3,68) =	5.42 ***	F(4,65) =	6.05 ***	F(4,65)=	5.93 ***	F(10,59)=	31.2 ***	F(5, 64)=	5.01 ***
Adjusted R^2			0.16		0.23				0.23		0.23

*** sig at 1% ** 5% * 10%

Table 6.5 Estimation of Export-sales Ratio

concentration– while remaining negative – now becomes statistically significant (at 5%). This result is consistent with a human capital interpretation – industries utilising more human capital have higher export-sales ratios. In addition, it is important to note that – while the estimated intensity of the standard intensity drops a little, from 0.28 to 0.24 – it remains statistically significant.

The remaining results in Table 6.5 provide some tests of robustness. Result set 3 performs the STATA® robust regression in which – as discussed in the previous chapter – all observations with a non-zero error term are weighted according to Cook's measure of distance. It can be seen that the results are little changed from set 2.

In a cross-section regression of the type considered in Table 6.5, one of the biggest sources of mis-specification is omitted variable bias where the omitted factor(s) are correlated with variables that are included. One way of addressing this issue is to introduce further variables which may control for some of the omitted factors. One of the most important omitted factors discussed in section 6.2 is the extent to which industries commit resources to innovation, frequently captured in empirical studies by R&D expenditures. To try and control for the problem of unobserved factors a set of sectoral dummies are included in result set 4. The sectors included are food, drink, and textiles (SIC 15-19), chemicals (SIC 23-25), metals and metal products (SIC 26-27), mechanical engineering (SIC 28-29), electrical and electronic equipment (including instruments - SIC 30-33), transport equipment (SIC 34-35) and other manufacturing (SIC 20-22; 36-37). An F-test of the significance of these sectoral variables shows them to be jointly insignificant. However, their inclusion does reduce the coefficient on ***relwage***, as well as making it statistically insignificant. Nevertheless both the intensity of standards use and industrial concentration retain their significance, although the coefficient on the former at least has been reduced.

The final result set in Table 6.5 considers the possibility that measurement contributes to the export-sales ratio over and above the impact coming through standards in general. In the final experiment reported, the intensity with which industries use instruments is included as an additional regressor. While the impact is estimated to be positive, it is statistically insignificant at conventional levels.

Table 6.6 turns to estimation of the import-sales ratio and net trade, employing the same set of explanatory variables as for the export equations in Table 6.5. Result set (1) corresponds to the second set of results in Table 6.5. Once again, the coefficient on the intensity of standard use is positive with an estimated elasticity which is very similar to that estimated for the export-sales ratio, suggesting that any impact on net-trade may not be large. The main difference in the results for imports is that the relative wage is now negatively signed but insignificant.

Result sets (4) – (6) of Table 6.6 consider net exports measured as the logarithm of the export import ratio. A surprising feature of the result is that the set of sectoral dummies is now significant. The sign on the intensity of standard use is statistically significant and negative, when the dummies are included (result sets (5) and (6)). As expected, there is a strong and statistically significant association between relative wages and the export-import ratio. Again, this is at least consistent with the UK having a comparative advantage in skill intensive manufacturing.

The final table of econometric results – Table 6.7 – considers whether there is any difference in the results according to whether the destination is the EU or not. The estimation here follows the same methods as in the total trade analysis, but is conducted for the period 1998-2002, i.e., after enlargement of the EU. Of course the non-EU trading partners sector contains a wide range of partner countries, including both developed (N. America, Japan, etc.) and less developed economies (China, India, etc.). While the results are generally similar to those above, it needs to be noted that standards intensity is particularly strongly related to imports from *non*-EU destinations. In fact it is in relation to non-EU destinations that industries which make a greater use of standards are those with a comparative disadvantage.

REGRESSIONS OF IMPORT-SALES RATIOS AND NET-EXPORTS

Result Set		(1)		(2)		(3)		(4)		(5)		(6)	
Dependent Variable		Log of Import-Sales ratio		Log of Import-Sales ratio		Log of Import-Sales ratio		Log of Export-Import Ratio		Log of Export-Import Ratio		Log of Export-Import Ratio	
Estimation Method		OLS		OLS		Robust Regression		OLS		OLS		Robust Regression	
Explanatory Variable	Identifier	coefficient	t-ratio Sig	coefficient	t-ratio Sig	coefficient	t-ratio Sig	coefficient	t-ratio Sig	coefficient	t-ratio Sig	coefficient	t-ratio Sig
Logistic of capital share	*lcapshare*	0.273	1.26	0.339	1.37	0.435	1.70 *	-0.047	-0.38	0.036	0.28	0.010	0.07
Intensity of standards use	*lsio*	0.279	3.46 ***	0.293	3.18 ***	0.279	2.92 ***	-0.040	-0.87	-0.123	-2.58 **	-0.112	-2.30 **
Adjusted industrial concentration	*c5_om*	-0.007	-1.10	-0.010	-1.36	-0.010	-1.34	-0.006	-1.67 *	-0.003	-0.86	-0.003	-0.79
Relative wage	*relwage*	-0.275	-0.70	-0.307	-0.65	-0.245	-0.50	1.171	5.28 ***	0.658	2.70 ***	0.694	2.77 ***
Sector dummy (SIC20-22;36-37)	*dum1*			-0.010	-1.36	-0.623	-1.69 *			-0.017	-0.09	0.260	1.38
Sector dummy (SIC 23-25)	*dum2*			-0.451	-1.27	-0.218	-0.64			0.536	3.15 ***	0.511	2.93 ***
Sector dummy (SIC 26-27)	*dum3*			-0.142	-0.43	-0.504	-1.16			0.567	2.62 **	0.544	2.45 **
Sector dummy (SIC 28-29)	*dum4*			-0.591	-1.41	-0.418	-1.17			0.633	3.57 ***	0.606	3.32 ***
Sector dummy (SIC30-33)	*dum5*			-0.463	-1.35	0.030	0.07			0.536	2.54 **	0.505	2.32 **
Sector dummy (SIC34-35)	*dum6*			0.086	0.21	0.305	0.61			0.205	0.83	0.163	0.64
Constant		1.375	3.66	0.316	0.66	1.786	3.20 ***	-0.038	-0.18	-0.645	-2.32 **	-0.613	-2.15 **
F-test of Sector Dummies				F(6,59) =	1.16	F(6, 59) =	1.08			F(6, 59) =	3.42 ***		2.58 **
No of obs		70		70			70		70		70		70
F-test of equation		F(4,65) =	4.38 ***	F(10,59) =	2.48 ***	F(10,59) =	2.13 **	F(4, 65) =	7.93 ***	F(10,59) =	5.93	F(10,59) =	4.8
Adjusted R^2			0.16		0.18				0.29		0.42		

Table 6.6 Estimation of Imports Sales and Export-Import Ratio

REGRESSIONS BY DESTINATION
time period 1998-2002

Result Set		(1)		(2)		(3)		(4)		(5)		(6)	
Dependent Variable		Log of EU Export-Sales ratio		Log of Non-EU Export-Sales ratio		Log of EU Import-Sales ratio		Log of Non-EU Import-Sales rati		Log of EU Export-Import ratio		Log of Non-EU Export-Import ratio	
Estimation Method		OLS		OLS		OLS		OLS		OLS		OLS	
Explanatory Variable	**Identifier**	**coefficient**	**t-ratio Sig**	**coefficient**	**t-ratio Sig**	**coefficient**	**t-ratio Sig**	**coefficient**	**t-ratio Sig**	**coefficient**	**t-ratio Sig**	**coefficient**	**t-ratio Sig**
Logistic of capital share	*lcapshare*	0.162	0.90	0.050	0.19	0.246	1.33	0.286	1.02	-0.067	-0.57	-0.240	-1.16
Intensity of standards use	*lsio*	0.274	3.79 ***	0.247	2.39 **	0.238	3.23 ***	0.461	4.10 ***	0.039	0.82	-0.214	-2.59 **
Adjusted industrial concentration	*c5_om*	-0.018	-2.91 ***	-0.023	-2.62 **	-0.013	-2.08 **	-0.012	-1.25	-0.006	-1.41	-0.010	-1.52
Relative wage	*relwage*	1.099	3.41 ***	1.421	3.09 ***	0.287	0.87	-0.095	-0.19	0.781	3.72 ***	1.498	4.07 ***
Constant		0.340	0.76	-0.071	-0.11	1.048	2.29 **	2.187	3.15 ***	-0.627	-2.15 **	-2.252	-4.40 ***
No of obs		70		70		70		70		70		70	
F-test of equation		F(4, 65)	7.68 ***	F(4, 65)	4.52 ***	F(4, 65)	4.45 ***	F(4, 65)	5.65	F(4, 65)	3.82 ***	F(4, 65)	6.15 ***
Adjusted R^2			0.28		0.1696				0.21		0.14		0.23

*** sig at 1% ** 5% * 10%

Table 6.7 Estimates of Export- and Import-Sales ratios and Export-Import Ratios

6.6 Concluding Discussion

This chapter analysed UK trade performance over the period 1993 to 2002 based on the UK trade flow data across 73 manufacturing industries. Three different dependent variables, namely the export-sales ratio, import-sales ratio and the export-import ratio were estimated separately, in order to capture the characteristics of trade performance in the long run. The explanatory variables considered the logistic of the capital share, the intensity of standards use, an adjusted industrial concentration ratio, and the relative wage. The fixed effect model has been chosen, and sectoral dummy variables have been used as well to control for possible unobserved factors.

As far as the various explanatory variables are concerned, the overall results confirm the relevance of standards for promoting markets. Put simply, the extent of both exports and imports is higher when more standards are present. Experiments with variables which were more closely related to measurement, either in the form of measurement related standards or the use of instruments, did not suggest any impact of measurement over and above that coming through standards in general. As far as the potential role of measurement or standards in generating comparative advantage was concerned, no such effect could be found. In fact the export-import ratio appeared to be negatively associated with standards use, an effect which seemed to be important for non-EU trading partners.

As far as the other variables are concerned, the empirical results do not suggest any association of either exports or imports with the logistic of the capital share, at least when relative wages are included. The positive association between higher industry wages and comparative advantage is consistent with a Heckscher-Ohlin type human-capital abundance explanation, but of course it may be that more competitive industries pay higher wages. High concentration ratios appear to be negatively related to export-sales ratios rather than import-sales ratios.

It is interesting to compare these results with Swann *et al.* (1996) – perhaps the first work to use econometrics to study the relationship between standards and trade in the case of the UK. Apart from the fact that this study was for an earlier period when standards had a more national orientation (and before the implementation of the EU Single Market Programme), this study focused on non-price competitiveness (aspects of quality such as product characteristics, after sales service and so on), using relative prices (price competitiveness) as one of the explanatory variables. The analysis of comparative advantage and specialisation in general and followed in this chapter, has no such control, because relative prices are endogenous to the 'deeper' explanations of comparative advantage. However, the positive role for standards as far as net-exports are concerned that was found in the earlier study, was not replicated in the analysis of this chapter.

APPENDIX

Appendix 6.1

Industry Categories Based on UK Input-Output Supply Use Table

SIC(92)	Industry Description
15.1	Meat products
15.2 + 15.3	Fish, fruit and vegetables
15.4	Vegetable and animal oils
15.5	Dairy products
15.6	Grain mill products
15.7	Prepared animal feeds
15.81 + 15.82	Bread, rusks and biscuit
15.83	Sugar
15.84	Cocoa; chocolate
15.85 to 15.89	Other food products
15.91 to 15.97	Alcoholic beverages
15.98	Production of mineral waters
16	Tobacco products
17.1	Spinning of textile fibres
17.2	Textile weaving
17.3	Finishing of textiles
17.4	Made-up textile articles
17.51	Carpets and rugs
17.52 to 17.54	Other textiles
17.6 + 17.7	Knitted and crocheted fabrics
18	Wearing apparel
19.1 + 19.2	Tanning and dressing of leather
19.3	Footwear
20	Wood and wood products
21.1	Pulp, paper and paperboard
21.2	Articles of paper
22	Publishing, recorded media
23	Coke, refined petroleum products
24.11 + 24.12	Industrial gases
24.13	Other inorganic basic chemicals
24.14	Other organic basic chemicals
24.15	Fertilisers and nitrogen compounds
24.16 + 24.17	Plastics and synthetic rubber
24.2	Pesticides
24.3	Paints, printing ink and mastics
24.4	Pharmaceuticals, medicinal chemicals
24.5	Soap and detergents
24.6	Other chemical products
24.7	Man-made fibres
25.1	Rubber products

Appendix 6.1 – cont.

SIC(92)	Industry Description
25.2	Plastic products
26.1	Glass and glass products
26.2 + 26.3	Ceramic goods
26.4to26.8	Bricks, tiles, cement
27.1 to 27.3	Basic iron and steel
27.4	Non-ferrous metals
27.5	Casting of metals
28.1	Structural metal products
28.2 + 28.3	Tanks, steam generators
28.4 + 28.5	Roll forming of metal
28.6	Cutlery and general hardware
28.7	Other fabricated metal products
29.1	Machinery for the production
29.2	Other general purpose machinery
29.3	Agricultural and forestry machinery
29.4	Machine tools
29.5	Other special purpose machinery
29.6	Weapons and ammunition
29.7	Domestic appliances
30	Office machinery and computers
31.1 + 31.2	Electric motors
31.3	Insulated wire and cable
31.4 to 31.6	Electrical equipment
32.1	Electronic valves and tubes
32.2	Television transmitters and apparatus
32.3	Sound or video recording apparatus
33	Medical, precision and optical instruments
34	Motor vehicles, trailers
35.1	Building and repairing of ships
35.2 + 35.4 + 35.5	Other transport equipment
35.3	Aircraft and spacecraft
36.1	Furniture
36.2 + 36.3	Jewellery, musical instruments
36.4 + 36.5	Sports goods, games and toys
36.6 + 37	Miscellaneous manufacturing

Source: Office for National Statistics (2004)

Appendix 6.2

Hausman Test

How can we decide whether to use the fixed or random effects model? Mundlak (1978) suggests an interpretation of the models which leads to an answer to this question. He suggests that in both models we should view the effects α_i as random. However, in the fixed effects model, estimation is conditional on the realised α_i in the sample, the random effects model estimates the model unconditionally but requires the assumption that the effects α_i are uncorrelated with the regressors X. When this assumption is valid, then the random effects model uses more information which makes it a more efficient estimator. However, if the assumption of no correlation between α_i and X is violated, then the random effects model leads to inconsistent estimates, whereas the fixed effects model is still consistent (Pierse, 2003).

Hausman (1978) first suggested the test to compare the fixed effects and random effects estimation for whether there is correlation between α_i and the regressors X, assuming that the idiosyncratic errors and explanatory variables are uncorrelated across all time periods. We can test the hypothesis:

H_0 : α_i are not correlated with x_{it}

H_1 : α_i are correlated with x_{it}

Under H_0 the GLS estimator is consistent and efficient. On the other hand, the within-group estimator is consistent whether the null hypothesis is valid or not since all time-invariant effects are subtracted out (Maddala, 2001). In other words, since the null hypothesis stated the coefficients estimated by the efficient random effects estimator are the same as the ones estimated by the consistent fixed effects estimator, if the result of Hausman test is not significant, then it is best to choose the random effects model, since it is more efficient. Otherwise, use fixed effects model, since it is consistent.

In this study, the first important thing is to choose the right model. Table A 6.1 below shows the result of the Hausman test. Accordingly, the significant P-value suggests that we should use the fixed effects model.

Hausman Test Result

	Coefficients			
	(b) FE	(B) RE	(b-B) Difference	sqrt(diag(V_b-V_B)) S.E.
t94	0.007	0.025	-0.018	.
t95	0.026	0.055	-0.029	0.002
t96	0.052	0.088	-0.036	0.004
t97	0.039	0.078	-0.039	0.005
t98	0.008	0.047	-0.039	0.005
t99	-0.021	0.015	-0.036	0.004
t00	0.005	0.035	-0.029	0.002
t01	0.005	0.023	-0.018	.

b = consistent under Ho and Ha; obtained from xtregar
B = inconsistent under Ha, efficient under Ho; obtained from xtregar

Test: Ho: difference in coefficients not systematic

chi2(8) = (b-B)'[(V_b-V_B)^(-1)](b-B)
= 33.89
Prob>chi2 = 0.0000

Table A 6.1 Hausman Test Result

Chapter 7

Conclusions and Discussion

This chapter provides a brief review of this thesis and discusses its implications and prospects for future research. Section 7.1 summarizes the main findings of the literature review (Chapter 3), the characteristics of the theoretical model (Chapter 4), and the empirical tests of the monopolistic competition model (Chapter 5), as well as empirical analysis of the patterns of trade in UK manufacturing (Chapter 6). Section7.2 identifies the limitations of this research and a few topics for future research.

7.1 Review: Measurement, Variety and Markets

Despite the widely recognised importance of technology for international trade and economic growth, only a few economists have started to explore the more specific mechanisms by which technological knowledge is not only created but, perhaps more importantly, it spreads and is used to enhance the activities of firms. The contribution of this thesis is toward the understanding of the knowledge which supports the creation of markets. These have been referred to as infra-technologies, pre-requisites to technological innovation (Temple and Williams, 2002b). The concept of measurement provides a coherent way of understanding an element of this supporting infrastructure which can be studied in a coherent theoretical and empirical context. The idea that measurement is central to the creation of markets and variety in particular is central to this thesis.

The creation of markets was of course also central to the ideas of Adam Smith explained how the wealth of nations depended upon the specialisation. But the advantages gained from specialisation – made famous in the pin factory example - owed nothing to specialisation according to comparative advantage but instead to the advances made possible from learning by doing and increasing returns at the level of the firm. Smith reckoned that a small factory making pins could produce many thousands of pins in a day. But the ability of the owner of the factory to sell those pins depended on the extent of the market. This was determined largely according to transport costs and Smith observed that in Europe the early generation of wealth was around the ports of the Mediterranean, around which the movement of goods was far easier than across land. But interestingly, it was not just the smooth conditions in that 'great inlet' that made the Mediterranean particularly important at an early stage "when, from their ignorance of the compass, and from the imperfection of the art of shipbuilding, men were afraid to quit the view of the coast, to abandon themselves to the boisterous waves of the ocean[74]". The lack of a measurement instrument therefore, at least according to Smith, partly determined the limits of early civilization in Europe.

More generally of course, and as transport costs and other barriers to trade have declined, other factors have come to be seen as important in limiting the extent of the market. Many economists today use the concept of transactions cost to describe the ease or difficulty of using the market to buy and sell. At the most general level one of the fundamental features of the measurement infrastructure which forms the analysis of this thesis is that it reduces transactions costs. As markets developed in Smith's view of the world, productivity grew and prices fell. Just as important – and recognised by Smith – was that expanded markets allowed for increased variety. It is here that the role of transactions costs may be particularly important, allowing firms to describe their products

[74] A. Smith Wealth of Nations, Book I (iii) Oxford: Oxford University Press, 1993. I am grateful to my supervisor for this reference.

in ways that are readily understood by market participants. In the examination of the measurement infrastructure in chapter 2 of this thesis, the role of standards is highlighted. It is shown that standards provide a main stanchion of the measurement infrastructure conveying technological information which reflects measurement, and the science of metrology provides terminologies, test procedures, certified reference materials, etc., which can support domestic industries and industrial development. Chapter 2 not only identified the important functions of standards with respect to measurement, but examined how standards, along with the use of instruments, can be used empirically. Both standards and instrument use are employed in the theoretical chapters.

Key Findings from chapter 2 include:

- The concept of measurement provides a coherent basis for considering the role of technology in a modern economy. The concept of the National Measurement System provides a useful way of studying economic activities related to measurement.
- National measurement systems can be seen in a hierarchical way with metrology and research into measurement proceeding down to the use of instruments in practical settings.
- Measurement leaves an empirical 'footprint' in the form of technical documents known as standards and in the extent to which industries use instruments. Both types of measure were used in the empirical analysis.

Despite the attention attached to Smith's analysis of the pin factory, it did not provide a major theme in the development of economic thought for many years. Increasing returns at the level of the firm are not consistent with the idea of perfect competition. Marshall however introduced the idea of 'external' economies in which the expansion of an industry shifted the average cost curves of individual firms. As a source of external economy, Marshall drew attention to the role of specialisation amongst suppliers, in other words, to variety. The costs of downstream firms are reduced if they have a bigger range of goods to purchase. The argument makes sense if the supplying firms are themselves operating with increasing returns, making for a trade-off between variety and costs. The possibility of analysing such a trade-off needed further theoretical developments in economics. First, the model of monopolistic competition developed by Joan Robinson and Edward Chamberlin in the early 1930s showed how competition and economies of scale could be analysed together and how the extent of variety depends upon the size of the market. Second, there was the extension of demand theory to include product variety and characteristics which came much later.

An important early use of the new tools of monopolistic competition occurred in the analysis of international trade. With the traditional theories of trade focusing on comparative advantage, the phenomenon of intra-industry trade – especially in the context of the growth of such trade in Europe – provoked considerable attention. The new models of trade considerably extended the understanding of this type of trade and provided the natural framework in this thesis for analysing the role of measurement as a support for the generation of variety. Measurement in the context of the development of international trade theory was considered in chapter 3, which provided a literature review of international trade theories based on a consideration of the impact of technology on trade patterns.

The literature review in chapter 3 identified four main genres of international trade theories – namely, comparative advantage models, technology based theories of trade, market structure models and dynamic comparative advantage models. As emphasised by Swann (1999), there are several important mechanisms through which development in measurement technologies impact upon trade flows, such as support for development of new products through generating new and better measurement techniques. Although the main consideration of this thesis is on the role of measurement infrastructure in developing variety and intra-industry trade, it is recognised that it may involve competitive advantage for the nation. The chapter noted that, beginning with the pioneering work provided by Swann *et al.* (1996), there is a small but growing literature which has studied and showed the relevance of standards for intra-industry trade. None of these had looked however at measurement in particular.

Key findings from chapter 3 include:

- Review of literature demonstrates the relevance of technology for understanding technology flows. This appears to apply even to models of static comparative advantage.
- Due to the fact that technology and the process of its creation and diffusion internationally exert a strong influence on patterns of trade, technological differences have been considered as an important determinant of trade flows in 'technology theories of trade' models.
- The 'new trade theory' focuses on monopolistic competition, product differentiation and economies of scale to explanation of increasing intra-industry trade between industrial nations.
- 'Learning by doing' and R&D become the main sources of the 'dynamic comparative advantage theory' model.

The decades of the 1970s and 1980s saw the development of the monopolistic competition model to the analysis of the phenomenon of intra-industry trade about which traditional comparative advantage models had had little to say. Much of the theoretical framework of this thesis can be traced to Krugman's intra-industry trade model (1979) and the extension by Lawrence and Spiller (1983) to consider two sectors, one producing goods where variety is important and the other where it is not. Chapter 4 provided a further development of this model in which the measurement infrastructure partly determines the costs structure of firms in the monopolistically competitive sector, through a public good effect in reducing transactions costs, lowering the costs of product differentiation and decreasing firms' total costs. However, making use of measurement infrastructure incurs costs in the form of measurement capital, e.g., investment in instruments.

Key findings from the model developed in chapter 4 include:

- Measurement infrastructure is welfare enhancing for consumers as it reduces the mark-up on wages.
- The relationship between product diversity and the measurement infrastructure is concave. In equilibrium, the marginal benefit of an extra unit of measurement

infrastructure, in the form of a cost reduction in capital outlays, is equal to its marginal cost in terms of investment on measurement capital. Although the formal mathematical model showed a concave relationship, there is every reason to believe that economies are situated on the upward sloping part of the curve.

- The proposition that when measurement infrastructure is strong, there is greater potential for intra-industry trade between two equally endowed countries.

The extent of intra-industry trade that developed among the western European economies in the 1960s and later was one of the factors that led international economists to give intra-industry trade such attention in the first place. With rather similar economic structures the comparative advantage models of trade suggested little advantage from increasing economic integration and declining trade barriers in Europe. The theoretical model of monopolistic competition developed to explain intra-industry trade suggested (rather like the Ricardian comparative advantage model) a benign picture of international trade – with little but positive implications: higher real wages increased product variety, and in some models increased economies of scale. The hypothesis that the strength of the measurement infrastructure systematically impacts upon intra-industry trade – over and above the market size hypothesis – was subject to testing in chapter 5.

The empirical model of intra-industry trade developed in chapter 5 considered intra-EU trade across 22 industries for 1998. This was motivated by the fact that countries in the EU have rather similar development levels making comparative advantage type trade less prevalent. More important however is the EU Single Market Programme, which has seen harmonization of standards across the EU. Therefore, measurement standards were considered as industry characteristics variable, only differing by industries, and to which all countries had access.

Key findings from chapter 5 include:

- A clear association between the strength of measurement infrastructure – as proxied by technical standards related to measurement - and the extent of intra-industry trade between industries.

- Average intensity of instrument consumption use in each economy pair has a positive and statistically significant impact on intra-industry trade.
- Unlike the traditional proxy of market size variable (GDP), this study looked at the specific measure of market size of each of the trading partners. This variable continued to show the expected results, providing additional evidence for the relevance of the monopolistic competition model.

Based on the UK trade flow data across 73 manufacturing industries between 1993 and 2002, Chapter 6 examined the pattern of trade in UK manufacturing, considering measurement and standards as an additional factor in a Heckscher-Ohlin multi-factor model. A comparison may be drawn between the results obtained from estimating the export-sales ratio, import-sales ratio and net trade balances over this 10 year period. The explanatory variable – in addition to measures of the intensity of standards use across industries – included variables reflecting both capital and human capital intensity and industrial concentration.

Key findings from chapter 6 include:

- The intensity of standard use by industry has a positive and statistically significant impact on both export-sales ratios and import-sales ratios observed in UK manufacturing industry.
- The pattern of specialisation in UK industry is consistent with it being a human capital abundant economy, but no evidence was found suggesting that physical capital abundance was an important factor explaining specialisation.

7.2 Limitations and Possibilities for Future Research

The research in this thesis has revealed a range of issues which suggest possible areas for future research. The last issue will be discussed in detail since the empirical analysis of this thesis focused on the UK and EU. The next logical step might be to extend the study to other countries – such as China, which being the emerging economic power of the 21st century, will be an important subject for much analysis. There is much interest in the examination of the trade performance of China, since it has developed fast in the last decades, surpassing the US as the world's second-largest exporter in 2006 behind Germany (Finfacts Business News Centre, 2007). China has made remarkable strides towards the establishment of a market economy. According to the World Trade Organization (2007), export growth from China rose 27% in 2006 alone, and is projected at current growth rates to overtake Germany as the world's biggest exporter during the course of this year (2008).

One of the main unresolved issues in this thesis is the problem created by data limitations. The quality and quantity of economic data play an important role in most empirical analysis, especially when very long time series, panel data and cross-section level data are utilized, and poor quality of data can lead to confusing or even incorrect insights. This problem affects the econometric analysis, and both dependent and independent variables are clearly subject to problems that relate to measurement. As far as the dependent variables used in the analysis used in thesis are concerned, the measurement of intra-industry trade provides an important example. A significant proportion of trade in manufactures is characterized by intra-industry trade in most advanced industrial countries. However, while the theoretical literature of intra-industry trade is mainly based upon the idea of horizontal differentiation, the trade of close substitutes of similar quality, actual intra-industry trade data (even at low levels of aggregation) probably covers much trade in vertically differentiated goods (trade in goods in the same industry which differ in terms of quality and for which consumers are prepared to pay). As for example, Greenaway *et al.* (1995) make clear for the UK, two-way trade in vertically differentiated goods is extremely important in practice. The pattern of vertical intra-industry trade is of course consistent with the traditional Heckscher-Ohlin endowment theory, i.e., the partner countries have common tastes and technology but trade arises due to the differences in factor endowments and factors requirements of products. Therefore, the greater the difference in relative factor endowments between the two countries, the greater the share of vertical intra-industry trade. Undoubtedly, this explanation is complementary to explanation based upon technology and innovation. Either way however, the concept of the measurement infrastructure should be just as important for firms wishing to differentiate their products vertically, either through the demonstration of superiority in terms of existing measurable characteristics, or for firms wishing to demonstrate the relevance of perhaps entirely new characteristics.

This thesis was unable to study the distinction between horizontal and vertical intra-industry trade. In the case of China however, it is unlikely that the distinction can be ignored. The prospect of rising living standards and rising real wages will mean that producers in China will not always be able to rely on price sensitive markets but will have to consider developing products that will support higher wages – i.e., moving 'up-market' - in ways that other parts of Asia have managed so effectively. According to Rumbaugh and Blancher (2004), China's international trade has expanded steadily since the economy policy reforms of 1979. Exports and imports have grown faster than world trade for more than 20 years and China's share in global trade has increased from 1% in 1980 to 5.8 % in 2003 (Rumbaugh and Blancher, 2004). Apparently, most exports goods are in unskilled-labour-intensive products such as apparel, footwear and toys alike. Capturing the characteristics of products produced in China and how they are changing should shed some light on the changes being observed in Chinese exports, imports and the net trade balance.

Some empirical studies of trade conducted at an aggregate level have begun to consider the distinction between vertical and horizontal intra-industry trade, basing themselves on observed unit values in trade, and the assumption that differences in unit values correspond to differences in quality. This could be done in the case of China, but it almost certainly needs to be supported by study at a more micro-level, using perhaps case studies of particular industries, or products, where the measurement of actual characteristics could be considered.

The question of the role played by measurement and standards for China's integration into the world economy by measurement and standards brings out difficulties in the independent variables used in the current thesis. For example, important questions are raised by the use of standards counts. What really matters is how standards are used and the extent of their use. What is the level of standards utilisation in China? Standard counts are of course only proxies for levels of use. While the counts used in the thesis may serve as useful proxies in the context of intra-EU trade where many of the standards originate, their relevance for China may be more limited. However it would still be useful to know whether they have a positive impact on China's intra-industry trade or whether (consistent with the evidence from chapter 6 which showed the strong association between non-EU imports and standards intensities for the UK) they serve as an important means of market access for Chinese producers.

A final question where measurement and standards may be important is related to China's intra-regional trade. With China undergoing transition from a central planning to a market economy during the last three decades, the regional disparities of China have become more apparent (Kwan, 2005; Cai *et al.*, 2002 and Keidel, 2007). In particular, a study by Keidel (2007) aggregated China's 31 provincial-level jurisdictions into 7 major regions and then compared trends in rural income and consumption from 1985 to 2005, concluded that the pattern of regional disparities has in fact worsened (Keidel 2007). Moreover, Naughton (2000) argued that China's geographic expanse and rugged topography means there are significant physical barriers to inter-regional trade which may raise some economic policies issues. In addition, Branstetter and Feenstra (2002) apply a political economy framework to China; in order to investigate the impact of foreign investment, one has to assume that there is no trade between Chinese provinces. On the other hand, according to Cutle *et al.* (2004), China played an important role in the expansion of –intra-Asian exports. These Asian countries consist of Japan, China, Hong Kong, Singapore, South Korea, Taiwan, Indonesia, Malaysia, the Philippines and Thailand. From 1985 until 2003, there have been significant movements in intra-Asian trade flows, which have grown at an average annual rate of 14%, almost double the growth rate of world exports of 7.5% (Cutle *et al.*, 2004). The lower transport costs, similarity in demand and economies of scale in production can be some important reasons accounting for increasing intra-Asian trade performances of China. As yet, the possible role played by measurement and standards in generating trade between China's regions could be a research topic of considerable relevance to the emerging policy debates.

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