Efficiency and ownership with reference to British ports

Liu, Zinan

~~PRODUCTIVE~~ EFFICIENCY AND OWNERSHIP

With Reference To British Ports

Zinan Liu

Department of Economics

Queen Mary and Westfield College

University of London

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ABSTRACT

This study seeks to investigate the empirical basis for the hypothesis, arising from the economics literature, that public enterprises are inherently less efficient than private enterprises, with reference to British ports which provide a comprehensive "laboratory" of mixed-ownership enterprises.

The relative productive efficiency of public ports *vis-a-vis* private ports is evaluated in terms of efficiency frontiers of the industry at a fairly high degree of rigour. By applying the techniques of efficiency measurement the various ways that a British port producer might depart from overall productive efficiency were systematically explored. These include: production on the interior of the production possibilities set; production in the congested region of the boundary of the production possibilities set; and deviation from the scale that arises from the long-run competitive equilibrium. As well as static productive performance, productive performance relative to dynamic production frontiers is also the subject of investigation.

Both mathematical programming techniques and econometric techniques are employed. To fulfil the tasks in the empirical analysis, the econometric approach has been enhanced in two ways. First, a less restrictive structure of production technology is specified in estimating efficiency frontiers in order to define parametric measures in a more meaningful way. Second, Solow's (1957) measure of productivity growth is reconsidered in a context of stochastic frontier functions, which enables us to translate efficiency gains over time into a movement towards frontiers and a movement of the frontiers.

As far as British ports are concerned we found no evidence for believing the inefficiency associated with public ownership to be unavoidable. The results cast serious doubt on the transformation in productive performance brought about by the port privatisation programme.

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Appendices

ILLUSTRATIONS

SYMBOLS AND ABBREVIATIONS

Some standard mathematical notations used in the text are explained as follows:

$=:$	$A:=B$	A is defined by B;
ϵ	$a \epsilon A$	a is an element of A;
$\subseteq$	$A \subseteq B$	A is a subset of B;
$\geq$		if X and Y ϵ R(m), then $X_i \geq Y_i$ for all $i=1,2,\ldots$
$>$		$X > Y$ if and only if $X_i \geq Y_i$;
R(m)		Euclidean space of dimension m;
R(m)+		$R(m)+:= \{x: x \epsilon R(m),\ x \geq 0\}+.\ I(Y;)$
$\|\cdot\|$		$\|X\|:= (\Sigma(X_i)^2)^{1/2}$, Euclidean norm of $X \epsilon R(m)$;
$\to +\infty$		$X \to +\infty$, X tends to $+\infty$

Abbreviations are explained where they are first introduced in a section and redefined when they appear in other sections.

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Chapter 1

Introduction

1.1 The Patterns of Port Ownership in the UK

There are well over 300 ports and harbours in the United Kingdom ranging in size and complexity from small river wharves and fishing harbours to more than 100 commercially significant port authorities, as illustrated in Fig 1.1-1. A striking feature of British ports is the diversity in the forms of ownership.

Port ownership in this thesis is defined in terms of who provides port facilities and services. A port basically functions as a meeting point for various transport modes such as maritime shipping, inland navigation, highway and railway transport, pipeline and aeroplane. A bundle of different facilities and services have to be provided in order to fulfil the basic function of a port. Broadly these can be categorised into three groups: 1) the infrastructure (land, water area, docks, locks, breakwaters, channels, navigational aids, etc.); 2) the superstructure (quay cranes, gantries, forklifts, warehouses, sheds, etc.) and 3) the services (cargo loading and unloading, storage, pilotage, towage, etc.). Since any parties, such as national government, local government, independent public entities and private operators, may be involved in providing port facilities and services, port ownership is not simply a dichotomy between private and public ownership as in many other industries. The allocation of the provision rights and hence the property rights for the infrastructure, the superstructure and services among various parties gives rise to different patterns of port ownership as shown in Fig 1.1-2.

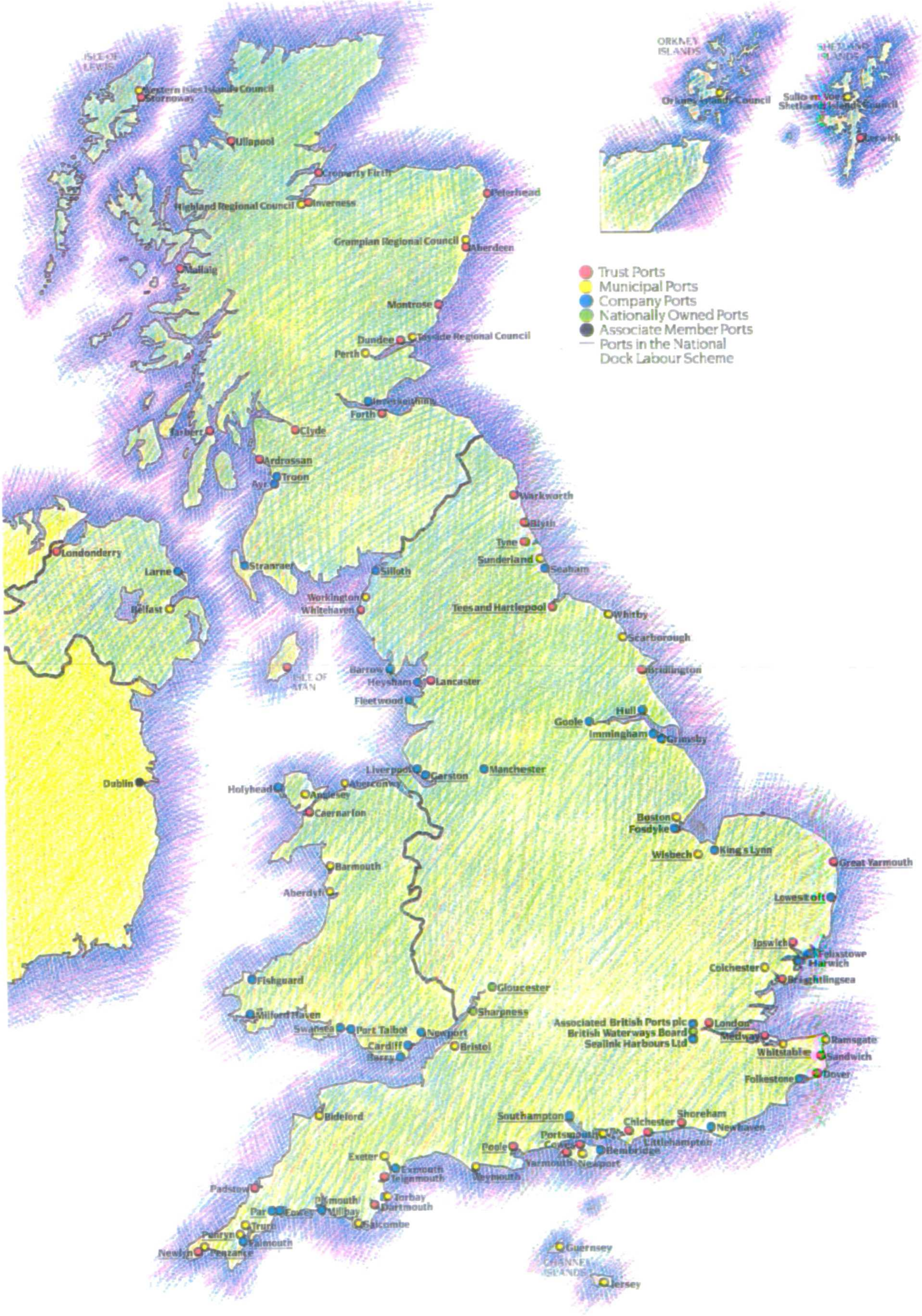

Fig 1.1–1 Port Ownership in the UK

in which the domain of the port authority is restricted to the provision of the infrastructure, while investment in the superstructure and port operation are the responsibility of licensed private companies. Thus we see that the frontier of public authorities rolls back gradually from Fig 1.1-2 (a) to (c). When the provision of all the facilities and services is left to the private sector as shown in Fig 1.1-2 (d) we have the case of a *private port.*

Since a public port authority usually owns the property rights to the infrastructure, its role in port activities is more than just a normal operator along with others. As well as being directly involved in port operations, a port authority is typically responsible for port planning, promotion and regulation of matters such as pollution, safety of life and property within the physical boundary of the port. A port authority is also potentially entitled to take advantage of its position to monitor and control the conduct of licensed private operators when necessary. In so doing a port authority is acting as a regulatory agency, designed to address undesirable features of market forces and to promote the interests of port customers and producers as a whole.

Therefore port ownership is better characterised in terms of the *status* and the *jurisdiction* of the port authority. In the status dimension port ownership represents *the degree of devolution* from the case of centralised administration to the case of comprehensive privatisation. In the jurisdiction dimension port ownership represents *the extent of public control* from the case of a pure public-sector port to the case of a pure private-sector port. Indeed port ownership can be viewed as a range of public policy instruments extending from *laissez faire* to government control.

Nearly all the types of port ownership can be found in the UK. Best-known are its trust ports, which constituted the most important form of port ownership in the UK before the second stage of privatisation in late 1980s and early 1990s. Also in the UK there are a number of private ports - a form of port ownership rarely found in the rest of the world. Private ports have now become the most important type of port ownership following the privatisation of some major trust ports (we shall return to this in the next section). In addition there are a small number of municipal ports and even one national port. Fig 1.1–3 shows the relative importance of the different forms of ownership in terms of traffic in 1990.

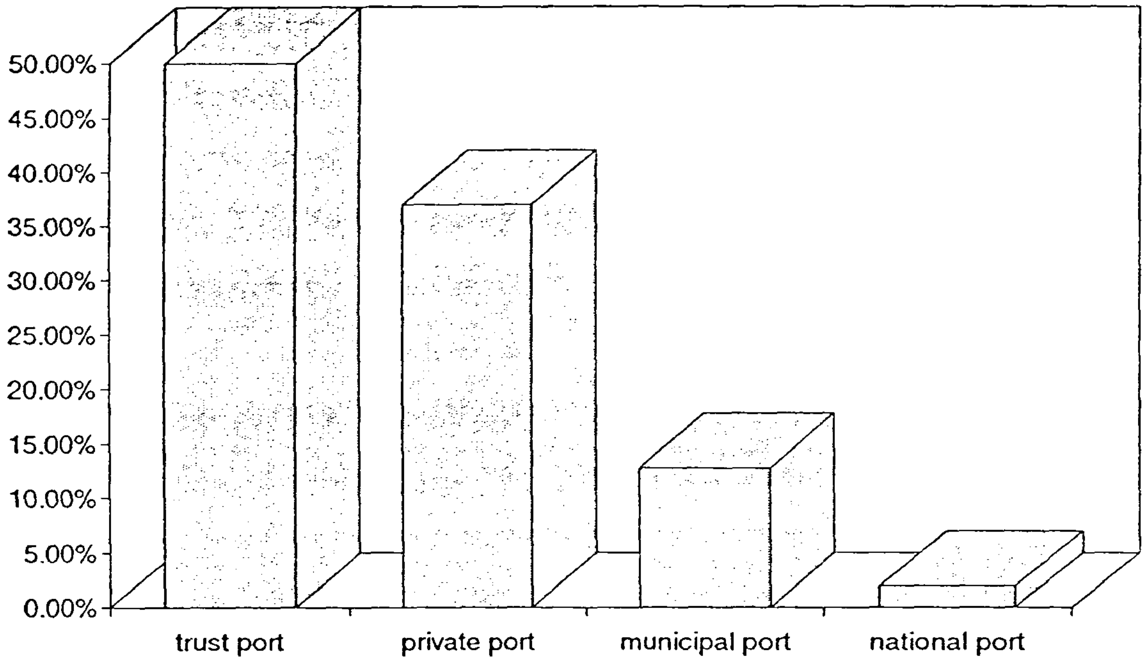

Fig 1.1–3 Relative Importance of Port Ownership in the UK 1990
Note: This is estimated on the basis of traffic data in *Port Statistics* 1990 published by Ministry of Transport and British Ports Federation. After privatising two municipal ports (Bristol and Boston) in 1991 and a number of trust ports (Clyde, Forth, Medway, Tees & Hartlepool and Tilbury) 70% of the cargo handling capacity of Britain's ports belongs to the private sector.

Trust ports have the characteristics of an autonomous port, but they are more independent than autonomous ports in France and Italy. Trust ports are set up by individual acts of Parliament or statutory orders, and owned and administered by self-governing bodies. The Secretary of State for Transport appoints most board members, including the chief executive of the port and also representatives from interested groups e.g. 'port users'. The remit of trust ports is typically, to provide a service for the import and export of goods by sea; to provide navigational conservancy; and to make the best use of their assets. Trust ports are not profit-making and were not permitted to engage in non-port activities until recently (Transport and Works Act, 1992). They are required to earn enough revenue to cover depreciation on assets at replacement cost, to pay interest on loans, and to provide for loan redemption. In years when they realise surplus revenue they must devote such a surplus to the furtherance of their statutory objectives, not the least of which, from the user's point of view, is a reduction in port dues and charges levied on ships and cargoes. Trust ports are usually capitalised by fixed-interest borrowing either from normal commercial sources, sometimes supported by government or directly from government. In the same way as other commercial undertakings trust ports are liable to national and local taxation. In 1990, 50 per cent of cargo volume though the UK ports was handled by trust ports. The trust ports which are included in the 10 largest British ports in 1990, as shown in Table 1.1-1, are London, Dover, Tees & Hartlepool, Milford Haven and Medway.

In 1990, 37 per cent of cargo volume through UK ports was handled by private ports. These include the Associated British Ports (ABP), Felixstowe, Liverpool, Manchester and a number of small ports. The list should now also include Tees & Hartlepool, Medway, Forth and Tilbury (a division of the Port Authority of London), as a result of the second wave of port privatisation in 1991 and 1992. Needless to say private ports are managed by boards which are elected by shareholders. Exceptional are London, Medway and Forth, which were privatised by staff buy-out. Typically private ports are profit-making, and company status enables them to diversify their activities into non-port areas such as investment in real estate. Private ports are capitalised by share-issuing and are liable to national and local taxation.

Municipal ports are owned by local authorities and managed by boards nominated by local authorities. The boards are divisions of the local councils rather than autonomous bodies. Like trust ports, municipal ports are non-profit making and are not free to diversify their activities. Municipal ports are usually required to generate revenue to cover total cost and to finance new port development. Some municipal ports are sometimes required to make a contribution to the budget of the local authority. Municipal ports are capitalised by local government at fixed interest rates and liable to national taxation (except the Corporation Tax) and local rates. The best-known municipal ports are Bristol, Sullom Voe and Ramsgate. The remainder are small. In 1990, 13 per cent of cargo volume through UK ports was handled by municipal ports.

Table 1.1-1 Top Ten British Ports 1990

Order	Ranging by Traffic[1] (Thousand tonnes)	Ranking by Trade Value[2] (£ million)
1	London (58,148)	Dover (36,256)
2	Tees & Hartlepool (40,248)	Felixstowe (25,048)
3	Grismby & Immingham (39,357)	London (13,298)
4	Sullom Voe (36,011)	Grimsby & Immingham (11,665)
5	Milford Haven (32,180)	Southampton (10,336)
6	Southampton (28,849)	Harwich (9,422)
7	Forth (25,433)	Liverpool (6,496)
8	Liverpool (23,183)	Ramsgate (5,625)
9	Felixstowe (16,448)	Medway (4,544)
10	Medway (15,901)	Tees & Hartlepool (2,905)

Notes:

[1] All Foreign and domestic traffic; See figures in the parentheses below each port.

[2] Imports and exports; See figures in the parentheses below each port.

Source: *Port statistics* 1990 published by Ministry of Transport and British Ports Federation.

In addition to the above categories, there are only 4 small ports remaining in the nationalised sector of the ports industry. A separate administrative unit responsible to the Government, the British Waterways Board (BWB), owns them and operates two of them. The share of the national port group in the total UK port traffic is negligible.

The main features of alternative forms of port ownership are compared and contrasted in Table 1.1-2. Unlike their counterparts in the rest of the world, for instance those in continental European countries, public ports in Britain are financially independent and are required to cover costs with no financial assistance from the Government. On the other hand they are free to set and vary their charges, subject only to the right of appeal of port users with regard to two specific types of charges (section 31 of the Harbours Act 1964). Since 1984 there has been no requirement for ports to seek government sanction for new investment regardless of size. Thus they operate as normal commercial undertakings in much the same way as private ports.

The extent to which port authorities participate directly in port operation in the UK also varies. Where the infrastructure and the superstructure serve general cargo they are mostly provided by the port authority. But in the case of bulk cargo private companies (oil, steel companies, etc.) other than port authorities are often responsible for a considerable proportion of the investment in the superstructure. Conservancy in most ports is provided by the port authority. In all ports cargo handling is mostly undertaken by port authorities and only 20 per cent is undertaken by licensed stevedoring companies. Pilotage used to be provided by regional pilotage authorities in some ports and by port authorities in others. Under legislation passed a few years ago the responsibility for pilotage was transferred to the local port authorities. The responsibility for lighterage and towage is fulfilled in some ports by private towage undertakings and in others by the port authority. By and large the duties and powers of port authorities are comprehensive. Thus the typical form of UK port ownership is very close either to the service port or the private port types as shown in Fig.1.1-2 (a) or (d).

Table 1.1-2 Features of Alternative Port Ownership

	Ownership
Company Port	Shareholders[1]
Trust Port	Public trust
Municipal Port	Local authorities
	Management
Company Port	Elected by shareholders
Trust Port	Appointed by the Ministry
Municipal Port	Appointed by local authorities
	Objectives
Company Port	Profit making
Trust Port	Public interests
Municipal Port	Local interests
	Managerial Constraints
Company Port	Shareholders, take over and bankcruptcy
Trust Port	Managerial change
Municipal Port	Managerial change and intervention by local authorities
	Pricing [2]
Company Port	No restriction
Trust Port	No restriction
Municipal Port	No restriction
	Investment
Company Port	No requirement to seek sanction
Trust Port	No requirement to seek sanction
Municipal Port	No requirement to seek sanction

Table 1.1-2 (Continued) Features of Alternative Port Ownership

	Financing
Company Port	Share issuing and borrowing from markets
Trust Port	Fixed-interest loan[3]
Municipal Port	Fixed-interest loan[4]
	Activity Area
Company port	Free to diversify
Trust Port	Legislatively restricted to port activity[5]
Municipal Port	Legislatively restricted to port activity
	Taxation
Company Port	national and regional taxation
Trust Port	national and regional taxation
Municipal Port	national and regional taxation[6]
	Right to Exit
Company Port	Not without the sanction of Parliament
Trust Port	Not without the sanction of Parliament
Municipal Port	Not without the sanction of Parliament

Notes:

[1] Three recently privatised trust ports (Medway, Forth and Tilbury) are owned by their management and employees.

[2] Under the Harbours Act (1964) section 31 port customers are entitled to challenge excessive port charges over costs.

[3] There is a borrowing limit imposed by Government.

[4] There is a borrowing limit imposed by local authorities, which is tighter than the borrowing limit imposed on trust ports.

[5] Under the Transport And Works Act published in March 1992 restrictions on the right of trust ports to diversify have been removed.

[6] Except Corporation Tax.

1.2 Evolution of Port ownership in the UK

The current status of port ownership in the UK is the result of an extended historical evolution involving the interplay of political, economic and technological influences.

Municipal ports were the earliest form of port ownership, this being the approach to port administration under the British Monarchy as early as the 10th century. Private ports were the product of industrial revolution and the railway era when railway companies began to build their own docks. The system of trust ports grew up in the 19th century, and provided a means of ensuring that harbour facilities in a given area were properly maintained for the benefit of the local shipping and/or fishing communities. Before World War Two most of the large ports in the UK were trust ports and the remainder were owned either by public or private companies or by municipalities. The general view then was in favour of trust ports because they combined the features of public ports with the advantage of autonomous status. Apart from diverse status of port authorities, another feature of port administrative structure at that time was that port facilities and services were provided by various separate private and public operators.

Since World War Two the UK port transport industry has undergone considerable organisational change. Many factors have influenced development within the industry. But political and economic events have been the major parameters in shaping the present institutional arrangements (Thomas,1981). Table 1.2-1 lists the principal landmarks of developments since 1945.

Shortly after the Second World War the Labour Government which was in office from 1945 to 1951 launched a vast nationalisation programme. Following the nationalisation of the Bank of England, the coal industry and the Air Corporation, several transport sectors including railways and their ports were nationalised with the Transport Act 1947.

Table 1.2-1 Principal Events in the British Port Industry 1945-1992

Time	Events
1947	Transport Act of 1947; Nationalisation of railway ports and formation of British Transport Commission;
1962	Transport Act of 1962; Reorganisation of British Transport Commission into British Transport Dock Board; Rochdale report of 1962;
1964	Harbours Act of 1964; Set-up of National Ports Council;
1965-1969	Amalgamation of ports;
1971-1972	Reconstitution of major port trusts;
1981	Transport Act of 1981; Privatisation of British Transport Dock Board into Associated British Ports;
1990-1992	Privatisation of Major Trust Ports and Municipal Ports.

Nationalisation, as a modern concept, was aroused on the one hand by the apparent exploitation of labour by capital, a strand rooted in socialist ideology, and on the other hand, by a growing awareness of the limitation of competition in those industries where a natural monopoly seemed to exist, a strand rooted in pragmatism (Thompson and Hunter, 1973, pp.3). We shall return to the second strand in detail in the next section.

Under the Transport Act of 1947 all properties owned by railway companies including their ports and docks were transfered to the British Transport Commission (BTC). The BTC had six assistant authorities, one of which, the Dock and Inland Waterway Executive was, in charge of ex-railway ports.

After this the organisational structure of UK ports remained unchanged until the transfer of the publicly owned ports from the Dock Division of the BTC to the newly created British Transport Dock Board (BTDB) under the Transport Act of 1962. Two factors led to the passing of the 1962 Act. One was the huge deficit of the BTC from its railway undertakings. The other was the inability of BTC to manage its vast undertakings, including railways, the ex–railway ports, long distance road haulage, road passenger transport, inland waterway transport and London passenger transport. Under the 1962 Act, the BTC was dissolved and separate public corporations in the form of various boards were established, each with its own power and jurisdiction and each responsible to the Minister of Transport. Most of the ex-railway ports were put under the control of BTDB and the docks linking with the inland waterway system were put under the control of British Waterways Board (BWB).

The subsequent structural changes were a direct result of the findings of the Rochdale Committee in 1962 (Rochdale Report, 1962). The Rochdale report made detailed recommendations with respect to each of the selected ports, with overall recommendations on a broad policy for the whole industry. The Committee suggested considerable benefits would be derived by combining many port functions under a single port authority. The Committee favoured the continued existence of independent trusts although it recommended revisions in the constitution of trust ports. It was also recommended that ports in direct public ownership should be replaced by trusts. To improve regional planning of port capacity and unity of command in the provision of the most important services, the Committee envisaged the amalgamation of certain existing ports, and proposed grouping them on existing estuary basis. As far as national planning was concerned the establishment of a national port authority was also envisaged which would be non-operational, would have responsibility for the overall development of UK ports, and would be given the necessary statutory powers to accomplish this.

The Conservative Government then in power rejected the idea of a national ports authority, and established in its place, a National Ports Council (NPC). The NPC was an advisory body which did not possess the power to enforce policies. It was established by the Harbours Act of 1964 and given the responsibility, subject to the Secretary of State's approval, for 'formulating and keeping under review the improvement and development plans of port authorities in the UK and encouraging and promoting more efficient management of port facilities and services'.

With respect to organisational structure the work of the NPC can be conveniently subdivided into two phases (Thomas, 1981). Between 1965 and 1968 the NPC implemented a scheme of port almagamation on an estuary basis and reconstitution of harbour authorities in line with the recommendations of the Rochdale Committee. The provision of cargo-handling services, pilotage, and conservancy was, until the early 1960s, very similar to that currently prevailing in continental European countries with the existence of non-operational port authorities while port services were provided by private or public operators. The arguments for the amalgamation of port undertakings on which most emphasis was usually laid were those concerned with priorities in investment, the avoidance of the wasteful duplication of resources, better planning in the distribution of traffic, more realistic charging schemes, and fuller use of port capacity. Following discussion with interested parties, larger port authorities were established under which port functions were concentrated. In effect this led to the enlargement of independent port trusts and the extension of the role of public ownership, since the type of port administration to emerge from rationalisation was determined by the predominant authority existing before.

The policy of rationalisation initiated by the Rochdale Committee and promoted by the NPC had the support of the law with the introduction of a more rigid and effective licensing procedure under the Harbour Act of 1966. According to the provision of the 1966 Act applicants for licences to operate as stevedores were required to satisfy two principal conditions. First, they must be competent to manage and supervise operation efficiently and they must be prepared to provide all necessary and proper equipment for use in connection with their work. This implies the needs for managerial expertise and investment on the part of the applicant. Secondly the applicant must be prepared to provide permanent employment to dock workers in accordance with the provisions of the local labour board.

The implementation of the policy of rationalisation in the provision of port services was also accelerated by two further important contributory factors. The most significant was the amendment (Dock Worker Act, 1967), in 1967, of the National Dock Labour Scheme introduced in 1947 (National Dock Labour Board, 1947), which required licensed employers to prohibit the continuing practice of casual employment. The other factor was the organisational and operational change, as well as new investment in specialised facilities which come with rapid technological advance in maritime transport industries (namely the introduction of cargo unitisation and the development of bulk shipments). Many companies were forced to leave the industry because of inability to cope with the new situation. The survivors often had to merge with others to acquire sufficient management expertise and capital for development.

As a result of these changes the number of licensed private operators fell significantly and port authorities assumed an increasingly important role in the provision of cargo handling and other port services.

From 1971 the NPC engaged in the reconstitution of major trust ports to make the boards smaller, to include more executive members and to ensure that members were appointed for their knowledge and experience rather that by particular bodies and interests.

Apart from the nationalisation of the ex-railway ports, successive Labour governments also initiated a number of unsuccessful attempts to bring the port sector as a whole under public ownership. The Ports Bill of 1969 was designed to establish a national ports authority to control all harbours handling more than 5 million tonnes of cargo a year. In August 1974 the Labour government announced that UK ports were to be nationalised, and a consultative letter outlining the proposed administrative structure was published. A second consultative document prepared in April 1975 proposed that all private commercial port undertakings should be transferred to public ownership. The suggested organisational structure was intended to increase central control of port management whilst preserving the maximum degree of local independence and initiative. These documents failed to become law with the defeat of Labour in the general elections of 1970 and 1979.

In the early 1980s the Conservative government launched a series of privatisation schemes which in the transport sector included the BTDB ports. The Conservatives believed that port users would be best served by allowing ports to compete with each other and by leaving the development of new port facilities to commercial requirement and market forces. It was not considered appropriate to attempt to lay down a detailed plan or framework for the operation and development of UK ports. In May 1981 the Transport Act 1981 empowered the Government to transfer the ownership of the BTDB from the public sector to the private sector with the new title of Associated British Ports (ABP).

The privatisation of BTDB was only the first series of privatisations. In January 1990, Boston, a municipal port, was privatised, which can be considered as the starting point of a second stage of privatization in the industry. Boston was followed in 1991 by Bristol – the largest municipal port, which was sold by Bristol Council to First Corporate Shipping. In August 1990 the then Prime Minister, in answering a Parliamentary question, said that the Government was looking into the possibility of an enabling bill aimed at the privatisation of the trust ports. In the mean time trust ports wishing to become limited companies have been encouraged by the Government to submit Private Bills to Parliament. Privatisation of trust ports was perceived as a means of increasing the ability of trust ports to diversify activities and to invest in port related transport operations. The opportunity offered by company status for commercial redevelopment in dockland areas and property development was seen as an attraction of privatization. Much of the growth of ABP has been attributed to property development. Company status would also facilitate a wider access to sources of capital for investment than is currently available to trust ports. Thus an important objective of port privatisation proposed at this time was particularly related to development needs. Under the powers of the Ports Act 1991 Tees & Hartlepool was taken over by a private company, which beat off a staff buy-out and led the way in the fight to privatise the trust ports. The sale embroiled the Government in controversy with Labour after it refused to overturn the offer by the private company. In March 1992 Medway, Forth, and Tilbury (a division of the Port of London Authority) were taken over by their management and employees in deals totalling about £90 million as the Government moved swiftly to offload ownership before the general election intervened to prevent sales. This time the Government avoided further damaging rows by agreeing to sell to local managements in regions where any other decisions could have had political repercussions. The list of trust ports privatised in 1992 also includes Clyde. It is certain that many other trust ports will follow sooner or later. These changes have brought some 70 per cent of the cargo handling capacity of Britain's ports into the private sector. Private ports which are rarely seen in the rest of the world are thus replacing trust ports and becoming the dominant form of port ownership in Britain.

To summarise: there have been two contrasting approaches towards port ownership and administration in the UK. While the interventionist approach, which has been historically influential, points to deficiencies of port markets and insists on some form of public ownership and some degree of central control of port development, the market approach currently adopted by the Government maintains that the efficient provision of port facilities and services must be left to the market mechanism. The shift from the interventionist approach to the market approach reflects a radical change of government industrial policy not only in the port sector but in other sectors as well. Historically, transport, energy and communications industries have been targets for public ownership in the UK. In recent years the UK has abandoned the public ownership approach by pursuing an active privatisation programme and at the same time setting up a number of regulatory agencies to monitor and control the behaviour of privatised companies when necessary. Unlike other industries which were nationalised concerns, public ports were already largely commercialised and decentralised, but this was not considered sufficient. The fundamental philosophy underlying the current public policy towards private business is that whenever competition is feasible, it is generally regarded as the optimal form of industrial organisation. When it is not, regulation is believed to be a more favourable instrument of public policy than public ownership. It seems to be assumed that the port sector falls into the category of industries where competition is feasible and that instances of market failure in the port sector are trivial. Thus it is believed that ports should be privatised without need for regulation of price and investment.

1.3 Port Ownership in Theory and Practice

The diversity in port ownership is not a unique British phenomenon. It reflects different perceptions everywhere about the relative importance of 'market failure' as compared with 'government failure' in port economy. The structures and policies vary not only between but also within countries all over the world.

Comprehensive private ports are not common. Apart from those in Britain, private ports in other countries, if any, are usually integrated within a major manufacturing enterprise (e.g. the oil port of Wilhelmshaven) without coming under the relevant port administration. Most major ports in the world are in some form of public ownership in the sense that they are administered either by local government (e.g. municipality or province) or central government, or by public autonomy. In the ports directed by the central government one can distinguish two groups: those administered directly by central government and those where management is entrusted to a separate administrative service or a similar body. Non–autonomous ports in France and Italy, all the major commercial ports in Greece and major ports in many developing countries are examples of the first group. The second group are represented by the 4 river ports controlled by the British Waterways Board (BWB) as mentioned earlier, which is responsible to the central government. Autonomous ports can be found in France, Italy, Britain, Ireland and Denmark and are the most important ports in the countries in question. Trust ports in Britain belong to this category and are probably more autonomous than similar ports in other countries. In the USA, Australia, Western European countries and Japan, municipal or local ports are the most important ones of the countries in question. Most of the principal world ports such as Rotterdam and New York belong to this category. By and large municipal or local ports seem to be the most popular form of port ownership in terms of the status of port authorities.

In terms of the jurisdiction of port authorities, the landlord or tool port, where the port authority provides the infrastructrue and superstructure and delegates port services to private sector companies, seems to be the most popular form. In the USA, Australia and Western Europe there is a common practice which distinguishes between public port activities (the provision of the infrastructure as well as port planning, promotion and regulatory activities) and commercial port activities (the provision of superstructure and cargo handling services). Service ports where a port authority or a private sector company performs all port activities are less common. Examples are ports in Singapore and Israel. In Britain, Ireland and Denmark port authorities perform almost all port activities.

Despite the diversity of institutional structures, by and large ports around the world have traditionally been among the industries in which government control, in the form of public ownership, regulation, financial assistance etc., is substantial. This is not exceptional even in the market-oriented economies. Goss (1983) advances four reasons why it is appropriate that major seaports in a country should be owned by the public sector. The first reason is that while property rights on land can be held by private individuals/firms the aquatory rights of the seabed and water column cannot normally be held by private individuals or companies – but an authority created by the government can own such rights. Secondly, national planning is needed in port development and, since ports are sub-systems of the total transport systems of the country, the public sector becomes the more appropriate agency to ensure integrated and co-ordinated planning of all transport services in the country. Thirdly, since the access channel, navigational lights and buoys and so on can be said to fall under the concept of public goods a public port authority becomes the most suitable organisation to provide such facilities for the common good. Fourthly, the public sector would have the flexibility and organisational adaptability to arrange mergers of a number of ports which can result in significant economies of scale. Moreover, the public sector could organise port facilities to be developed on a selective basis taking into account special, regional, local and national requirements.

There can be other arguments for ports being owned in the public sector. One is based on the fear of market power that ports may enjoy because of their exclusive location (local monopoly) and unavoidable concentration in port traffic (natural monopoly) especially for container and bulk shipments. This permits monopoly pricing and profits, deadweight losses of welfare and the absence of any pressure to keep costs as low as possible. Indeed, as the result of adopting modern shipping and cargo-handling technology, which are believed to exhibit substantial economies of scale, both the number of ports and the number of terminal operators have been reduced dramatically in many countries. The actual behaviour of port operators in this situation is thus of interest. Goss (1982) outlined an interesting example of this in Australia, where there are only a very few firms handling general cargo or operating container berths. Two stevedoring firms with substantial market shares were studied in some depth by the Australian Prices Justification Tribunal. A report was produced suggesting not only unjustified high port charges but also prevalent inefficiencies and excessive costs associated with these firms which could be linked to a lack of real competition.

Another argument is based on a strong doctrine which underlies port policies in continental European countries, the USA and many developing countries. It is believed that the national and regional economy can derive considerable benefits from the existence and development of ports such as accessing foreign markets, increased international trade or trans-shipment trade, reduced transport costs, and attracting and stimulating industries which in turn creates jobs, as well as personal and business income. Ports are thus viewed not as discrete commercial entities, but as components of the regional infrastructure acting as catalysts for regional development. The benefits derived from the provision of port facilities and services are dispersed throughout the population and are not fully reflected in the accounts of private operators or commercialised public ports.

In recent decades, however, there has been increasing dissatisfaction with the perceived poor performance of nationalised industries and frequent failure of state control. Privatisation policies, as attempts to reduce the role of government, are currently in progress the world over. Port industries are not excepted and ports entirely run by government are considered to be more expensive and less efficient.

The conviction that public ownership is synonymous with productive inefficiency is often rationalised in two ways in theories of industrial economics. First of all, the transfer of ownership from the private to the public sector (or vice-versa) results in a change in managerial incentive structures. Viewed from the perspective of the principal-agent theory, one can distinguish two effects (Vickers and Yarrow, 1989). One is the change in the objective of the principals (shareholders in the case of private enterprises, the voting public in the case of public enterprises). The other is the change in the arrangements for monitoring the performance of management. The managers of private enterprises will be concerned with meeting the requirements of the shareholders and may be faced with threats of take-over and bankruptcy, whereas the managers of public enterprises will concentrate on the satisfaction of ministerial objectives. While the capital market for corporate control is not perfect, it is regarded as more effective than the public monitoring system, which is subject to multiple levels of hierarchy and is vulnerable to goal displacement. Thus private enterprises are hypothesized to be in general more productively efficient than public enterprises, though the former tend to be less allocatively efficient than the latter.

Secondly, public ownership was one of the main solutions to the problems of natural monopoly that arose in industries where competition was assumed to be impossible or undesirable. However, there has been increasing awareness that competitive forces were too much neglected when they have a useful role to play. The competitive force provides a spur to productive efficiency as well as serving a mechanism conductive to allocative efficiency. The absence of competition under public ownership is thus seen as explaining the correlation between public enterprises and poor productive performance.

With these considerations in mind it is then hardly surprising that the esteen of public enterprises is at a low level and privatisation has become a world-wide phenomenon. Port privatisation can be achieved in two different ways. In most countries the privatisation process is limited to the provision of the superstructure and services and takes the form of the tool port or landlord port as in the case of many successful world ports such as Rotterdam, New York, Antwerp and Hamburg. It is believed that ports are better operated privately. Port activities such as cargo handling, warehousing, towage, lighterage and pilotage (whether pilotage should be provided by a public authority or a private-sector company is still controversial in many countries) can be readily catered for by private-sector companies. There has also been a tendency in many countries to increase the share of private investment in the provision of terminals as much as possible in order to ensure efficient management on the part of operators. But it is also considered in these countries that the involvement of government in ports is indispensable and the existence of public authorities is necessary. This can be justified by the arguments based on the potential for market failure which may arise in port industries as mentioned above.

In contrast to the classical pattern in other parts of the world, port privatization in Britain is comprehensive and involves the transfer of the whole port ownership from the public to the private sector and the possibilities for market inefficiencies are assumed to be trivial.

In spite of their different perceptions of the relative importance of 'market failure' as compared with 'government failure' in port economy, the consensus of both approaches to port privatisation is that in practice public ownership is inherently inefficient.

1.4 The Plan of this Study

This study seeks to investigate empirical evidence for the hypothesized productive inefficiency inherent in public port ownership *vis-a-vis* private port ownership with reference to British ports.

The results of this study can have important public policy implications. If one believes that there are many instances of both 'market failures' in seaports, for example, in the process of planning, supplying 'public goods' and controlling externalities, and 'government failure', i.e. productive inefficiency, the dilemma for public policy is a trade-off between allocative efficiency and productive efficiency. But if public ports are not necessarily inferior in productive performance or if public ports can be made more efficient through other means without changing their ownership status, such a trade-off will not be necessary.

The usual arguments against public ownership are made on general grounds and are not entirely relevant to ports. Firstly, Vickers and Yarrow (1989)'s notion of public enterprises corresponds to those in nationalised industries, and hence their theoretical analysis about the incentive structures under alternative forms of ownership from the perspective of the principal-agent theory which can be problematic when applied to port industries where public ports are of several forms, including trust port, municipal port and national port. One should examine the principal-agent relationship under different types of public port ownership as compared with that under private ownership before one can be certain about the impact of port ownership on productive efficiency. Secondly, competition rather than ownership *per se* is an overriding factor in generating efficiency. The size of efficiency gains from port privatization largely depends on the structure of the port market. But there is immediately a question as to whether port competition is workable given modern port technology which is believed to exhibit substantial scale economies.

The objectives of privatisation in the port transport industry as in other industries are many and varied. But at the micro-economic level the most important objective of any restructuring has been the promotion of increased economic efficiency, as privatisation is largely motivated by dissatisfaction with the productive performance of publicly owned ports. It has been more than 10 years since the Conservative Government first launched its port privatisation programme. Within that time Britain has become the only country in the world in which the private sector dominates the port economy. Crucially, has port privatisation transformed the industry into a paragon of efficiency? To date, however, there is little concrete evidence on the impact of the transformation upon port efficiency. The private port Felixstowe is considered as an example of outstanding success amongst British ports. From virtually nothing the port has grown to become number one in container traffic by a wide margin. But the growth of Felixstowe may well be attributed to its non-scheme status while its major competitors such as London, Liverpool and Southampton were hampered by labour problems. The overall trend of ABP ports has been one of an improvement in profits since they were privatised. But much of the growth of ABP, for example, valued at £60 millions in 1983 but valued at £490 millions in 1990, has been due to property development.

The number of performance studies of alternative forms of port ownership is sparse. To the author's knowledge the only serious study of this kind was done by Goss (1979, 1). Based on his visit to the principal world ports he was surprised to arrive at the conclusion that different port administrative systems can be equally efficient. As an example he mentioned the port of Hong Kong and the port of Singapore, with similar geographical environments and comparable cultural traditions, but taking exactly the opposite philosophies regarding the operation of their ports. Whereas in Hong Kong the private sector is dominant, in Singapore the port authority holds all the operations. Interestingly both ports are renowned for efficiency. Goss believed that if the port of Hong Kong and the port of

Singapore were to be run in any other way it would be so much in contrast with the whole of their respective forms of Government that it would become extremely difficult to operate. It seemed to him that the main factor is that the port system should be

> appropriate to the general system of government and the beliefs of people even though the latter is expressed as over-simplified slogan.[pp.47]

and therefore

> It is a serious error to transplant port organisations as if they were mechanical rather than social bodies...
> There is no concept of "best port" which might be considered ideal and applied to any places.

While Goss investigated the relationship between port ownership and efficiency in a global context, this study will examine the same theme in a British context.

There is no shortage of empirical studies to compare the performance of public and private enterprises in general. Having surveyed US studies, Vickers and Yarrow (1989, pp.40-1) find that, in industries such as electricity generation and distribution and water supply, where there is little competition and extensive regulation, there is no conclusive evidence. Where competition is significant, there is some evidence that private enterprises perform better, but the existence of competition tends to limit the differences in efficiency that persist for any appreciable period. In the UK, early work by Pryke (1971) indicated that the efficiency of public enterprises was generally superior to that of private enterprises in the first two decades after the war. But subsequent investigation of performance in the 1970s (Pryke, 1981) reversed this finding. Thus the results of this empirical literature have been mixed and there is no firm ground for believing that private firms perform better.

As Vickers and Yarrow stress, methodological problems abound in all empirical comparisons. One problem in these studies is that like is not always compared with like. This problem will be overcome in this study. The British port transport industry, which provides a fairly comprehensive "laboratory" of mixed ownership enterprises, appears to offer a good prospect for a comparative study of port ownership and administrative structures. An ideal comparative study is a like-with-like one, to put comparison in a setting of other things being equal in order to identify the major issues. Obviously UK ports operate under same market conditions and share the same political system, cultural tradition and geographical environment. Moreover public ports in Britain are well-known for their financial independence so that they are able to pursue a professional business approach just as much as private ports. In addition, UK ports provide an interesting case of "mixed markets" where public enterprises compete with private enterprises, which is an issue addressed in a relatively small literature.

Another problem of previous studies is the reliance upon variables that are easily observable, such as profitablity, factor productivity, and unit cost. These measures need not bear a close relationship with efficiency and some of them may even lead to a bias in favour of private ownership. An important feature of this study is to measure productive efficiency directly to a fairly high degree of rigour rather than use any other approximate measures. Measures of productive efficiency in this study are constructed in terms of Farrell (1957)'s *frontier production function*, which is consistent with the underlying economic theory of optimising behaviour.

Since the core of our investigation is concerned with productive efficiency, it is desirable to spell out its meaning at this point, though formal definitions and more explanations will be given later. In general, economic efficiency corresponds to Pareto optimality in resource allocation. There are two kinds of resource allocation going on in an economy. One is the resource allocation between economic agents (e.g. firms) through market mechanisms. The other is the resource allocation within economic agents (e.g. firms). Economics is supposed to deal with the issue of efficiency. But in the framework of microeconomics the meaning of allocative efficiency is narrowed to concern the first kind of resource allocation only, while "allocative efficiency" related to the second kind of resource allocation is not usually discussed in any detail. However, an economy will not be Pareto efficient if the second kind of resource allocation is inefficient. The second kind of "allocative efficiency" is known as productive efficiency, which can be defined relative to frontier production functions. A frontier production function simply represents the most productive technology currently available. A firm is said to be productively efficient if the firm succeeds in exploiting maximum production possibilities given by the frontier technology, i.e. the maximum possible level of outputs given inputs or the minimum possible level of inputs given output. A firm is said to be productively inefficient if the producer fails to exploit the maximum production possibilities given by the frontier technology. There are a number of possible ways that a firm might be productively inefficient. We are particularly interested in what follows:

(1) *purely productive inefficiency*: this refers to *X-inefficiency* and *technical inefficiency*. X-inefficiency arises from failures to realise the maximum production possibilities of the current technology in use, as a result of motivational deficiency at both management and worker level. It is thus managerial inefficiency. Technical inefficiency arises from the difference between the current technology in use and the most productive technology currently available. It is managerial inefficiency at least in the long run;

(2) *congestive inefficiency*: this could be a form of inefficiency in transportation. Congestion inefficiency occurs when a firm is not free to dispose of one of the inputs for one reason or another. As a result, the amount of the input in use is so excessive relative to other inputs that the marginal productivity of the input becomes negative. One suspected cause of congestion inefficiency in British ports was the National Dock Labour Scheme;

(3) *scale inefficiency*: a firm is said to be scale inefficient if the firm fails to operate on the optimal scale which maximises "average productivity" which would occur in the long-run competitive equlibrium. Scale inefficiency is not necessarily

inefficiency in private sense. But it is undesirable from the social point of view.

These three types of efficiency are mutually exclusive and exhaustive, meaning that a firm can be inefficient in any one way, any two ways, or in all three ways, but in no other way. Thus purely productive efficiency, congestive efficiency and scale efficiency are said to be components of *overall non-price productive efficiency*. The composition of productive efficiency in this way enables us to investigate the productive performance of firms systematically.

The concept of overall non-price productive efficiency and its components mentioned above are static in the sense that they are measured against a fixed production frontier in a given period of time. The production frontier, however, shifts and hence the set of efficient input and output combinations widens and new possibilities emerge because of technological development. A firm is more progressive or more dynamically efficient than another if it improves efficiency, relative to the shifting frontier, faster than the other. While it is important to make efficient use of resources at any time, it is *dynamic efficiency* or *progressiveness* that counts in the long run. This should be a matter for concern as well as *static efficiency* when we are talking about the comparative efficiency of alternative forms of port ownership.

We commence, in chapter 2, by providing a theoretical perspective for the possible effects of port ownership on efficiency. The analysis will focus on the degree of port competition and the incentive structures of port management under alternative forms of ownership, since the productive efficiency property of private-sector companies is often justified in these two ways. We will also provide a model drawing on the theory of spatial competition to compare the efficiency of pricing and investment decisions under alternative forms of port ownership. Chapter 2 thus offers a balanced text on the relationship between port ownership and economic efficiency, though our empirical analysis is concerned with productive efficiency only.

Chapters 3-4 provides estimates of productive efficiency, both overall and by components, for sampled British ports during the period 1983–1990. There are two competing approaches on how to construct frontiers. The first approach is deterministic on the assumption that the maximal output (given the level of inputs) or the minimal set of inputs (given the level of output) can be attained without error. The deterministic approach is often argued to be consistent with economic theory. Furthermore it is non–parametric and imposes no explicit functional forms by using mathematical programming techniques. However, it will over– or under–estimate the true extent of inefficiency if the data is contaminated by statistical noise (as always). The second approach is stochastic, assuming that the maximal level of output or the minimal level of inputs is random rather than exact. This allows statistical noise to be distinguished from true inefficiency. But this approach using econometric techniques is parametric and may impose an unwarranted structure on the frontier technology. Unless panel data is used it has to assume an explicit distribution function for inefficiencies as well. Since econometric models should be presumed to be misspecified (Gilbert, 1986), it is possible to argue that efficiency estimates derived from sophisticated stochastic frontier models need not be closer to the true extent of inefficiency than those derived from deterministic frontier models. Thus each approach has its limitations and each can be defended. To base solid conclusions on empirical evidence both approaches will be employed. Thus productive efficiency of British ports is estimated relative to a deterministic frontier in chapter 3 and relative to a stochastic frontier in chapter 4.

Compared with the deterministic approach using mathematical programming methods, the stochastic approach using econometric techniques is less solid. To enhance the stochastic approach the efficiency frontier of the British port industry is modelled using a less restrictive structure. An attempt is made to define purely productive efficiency, congestive efficiency and scale efficiency in the parametric framework. The construction developed enables us to evaluate the productive efficiency of British ports relative to a stochastic frontier in a systematic way similar to the deterministic approach.

In chapter 5 the dynamic efficiency of British ports is estimated. To do this we have developed a measure of total factor productivity growth in terms of a stochastic frontier production function, which translates efficiency gains over time in a different way from Solow's (1957) approach. It is shown that productivity growth over time can be more meaningfully decomposed into technical progress and efficiency improvement.

In chapter 6 the study is brought to its conclusion by examining empirical evidence on the relationship between port ownership and productive efficiency in the British port industry.

Chapter 2

Efficiency and Port Ownership:
A Theoretical Analysis

The efficiency implications of port ownership depend on the degree of port competition and the relative effectiveness of different monitoring systems associated with ownership. This chapter therefore analyses port market structure and management incentive structures under alternative forms of port ownership.

Port markets are known to be oligopolistic. Technological development in the port sector is believed to weaken competitive forces further. Therefore there are serious doubts as to whether port competition is sufficient to ensure efficiency. It is perfectly possible to argue within an orthodox microeconomics framework that, in the context of monopoly, public management will do better in terms of economic efficiency than private management (Vickers and Yarrow, 1989, pp.1). Section 2.1 thus investigates the structural features of port markets given current port cost and demand conditions. As far as the British port industry is concerned, we find no evidence to suggest that the economies of scale formed in modern port and maritime transport technology are so pronounced that the scope for port competition has become limited.

While this finding could mean that port competition is sufficient to ensure satisfactory performance by private ports in terms of both allocative and productive efficiency, it would not neccessarily imply substantial efficiency gains from port privatisation. Unlike in other sectors, port privatisation is not seen as a means of introducing new competition. UK Government port policy has been fairly liberal even before port privatisation. Public ports of various forms have been required to be self-financing and have been largely commercialised. In such circumstances, public ownership and competition are perfectly compatible with each other. In mixed markets where public ports and private ports compete productive performance depends very much upon managerial incentive structures. Section 2.2 then compares and contrasts the managerial incentive structures inherent in alternative forms of port ownership from the perspective of principal-agent theory. We conclude that port privatisation in Britain is unlikely to improve the managerial incentive structure significantly, since the general defects of a public monitoring system are largely reduced for trust and municipal ports because of their autonomous and decentralised nature. If we accept that a change of port ownership neither enhances competition nor improves incentive structures significantly, we will not be surprised if there is no significant difference in productive performance.

Recall that port ownership represents the degree of devolution as well as the extent of public control. Transfer of port ownership from the central government sector to the local government sector or to the private sector implies decentralisation of pricing and investment decisions. Here the misgivings of interventionists not only point to monopoly pricing but also to potentially undesirable port development in the absence of conscious planning by a central agency, whereas the fear of free marketeers is the ineffectiveness, inaccuracy and inefficiency of central planning and co-ordination. In section 2.3 the pricing and investment performance of decentralised public and private ownership as compared with centralised public ownership is modelled in a simplified setting. We argue that as long as public ports under indirect ownership are required to maximise the sum of producers' and consumers' surplus, port decentralisation does not worsen allocative nor investment performance. Another interesting result that emerges from the analysis is that port privatisation is likely to lead to higher port prices as compared with the social optimum, but the resultant allocative inefficiency is negligible and the undesirable economic effect is mainly distributional. A more serious welfare loss due to privatisation, however, is likely to be under– or over–provision of port facilities.

2.1 Structural Features of Port Markets

Market structure is important because the structure determines the behaviour of firms and that behaviour in turn determines the performance of the industry. Market structure includes such elements as product differentiation, market concentration on both the supply side and the demand side, and entry conditions.

Location differentiation

The product of a port is a bundle of services, such as cargo-handling, warehousing, pilotage, towage and many other complementary services. Port services differ from port to port in many aspects, including quality of facility, turnaround time, the rate of cargo damage and pilferage, the range of complementary services available and so on. The most important element distinguishing one port from another is port location, which has an important implication for port market power. Consider a line-segment hinterland along the horizontal axis in Fig.2.1-1, where cargo is uniformly spread out. The uniform distribution of port traffic implies that the distance from either port represents the volume of port traffic as well. Thus, for example, if the most distant customer of port 1 at O locates at a distance X from the port, the port throughput is X as well. The port services are supplied by two ports at either end of the hinterland, O and C, but are identical in all other aspects. Port price is P_1 = OF charged by port 1 at O and P_2 = OG by port 2 at C. In addition to this, it is assumed that inland transport cost is t per unit of cargo and per mile in both directions and represented in Fig 2.1-1 by the gradient of the sloping lines. The customer whose cargo origin or destination is at a distance X from the port at O has to pay inland transport cost per unit of cargo tX if the traffic goes through port 1 and $t(OC-X)$ if the traffic goes through port 2. Assuming t is constant, the total transport costs per unit of cargo the customer will pay at a distance X from port 1 is P_1+tX or $P_2+t(OC-X)$. This is given by the height of the sloping lines. Naturally the customer will choose to ship his cargo from the port with lower unit transport costs. The point D where the sloping lines intersect corresponds to a marginal customer who is indifferent between shipping his cargo through either port. Customers to the left of the marginal one will choose port 1 and customers to the right will choose port 2. Given a common reservation price R, however, only the customers whose cargo is spread over OA and BC will remain in the market whereas the customers whose cargo spreads over AB will be prohibited from the market by transport costs. The market is in effect segmented into two. Each port has a monopoly over its exclusive hinterland because of its distinct location.

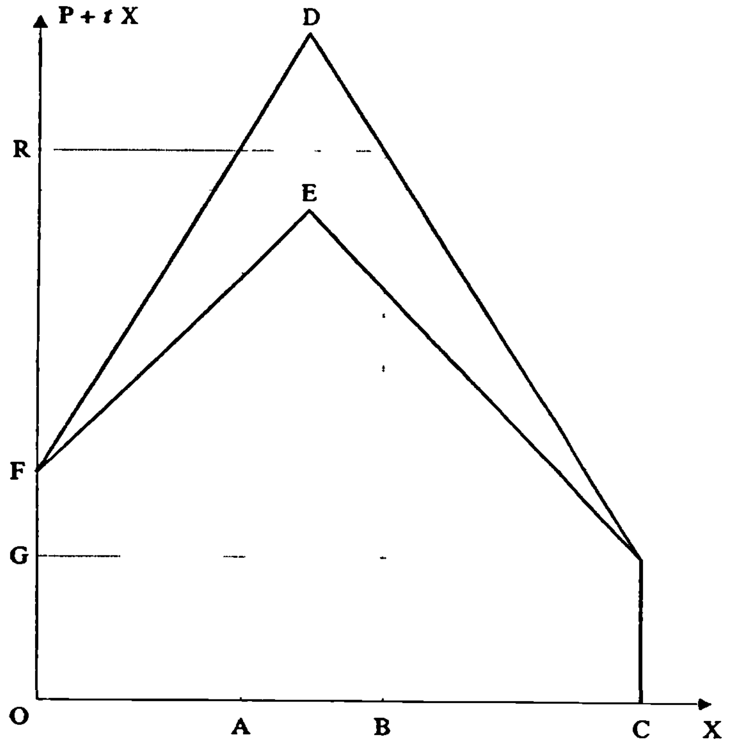

Fig 2.1-1 Location Differentiation and Local Monopoly

The local monopoly that a port enjoys stems from inland transport costs, which are determined by the distance from a port and the unit inland transport cost *t*. Obviously, if two ports are close enough so that their markets are no longer insulated from each other, the market structure will be changed from monopoly to duopoly and the ports will have to engage in spatial competition. A change in *t* will have the same effect. This can be seen by imagining a reduction in *t* which causes flatter sloping lines to intersect below the reservation price, say, at E, so that no customers will now be excluded from the market. Another effect of a change in *t* is to change price elasticity of demand facing the port. When *t* is higher, the sloping lines are steeper and port customers will be less sensitive to changes in port prices because the proportion of port charges in total transport costs is less significant. On the other hand, when *t* is lower, customers will be more sensitive to changes in port prices. Thus with high inland transport costs ports enjoy local monopoly in the sense that they serve an insulated market and face inelastic demand.

The degree of local port monopoly is country– or even area–specific, being a function of the geographical separation of the ports, the configuration of the inland transport system and the nature of the trade. Its long coast line endows Britain with a large number of seaports and they are connected with their hinterland by a well–developed inland transport system. It is likely that for Britian sloping lines are relatively flat. Also British ports are quite close together and in consequence the demand for individual British ports is likely to be relatively elastic and local port monopoly power is therefore probably limited.

The degree of local monopoly can be eroded by a reduction in inland transport costs. Such a reduction can be achieved by improving inland transport infrastructure and by introducing new cost–reducing transport technology. Indeed, with the development of transport technology, e.g. specialisation and containerisation, unit inland transport costs in real terms have become much lower, and in Fig. 2.1–1 this gives flatter sloping lines. As a result, the demand facing individual ports is more elastic on the one hand, and port markets are enlarged and ports are brought into spatial competition with more distant ports on the other. Since inland transport cost and transit time have become so much lower, cheaper and more efficient, importers and exporters can operate just as efficiently and cheaply through relatively distant ports as through local ones. A favourable location is no longer sufficient to guarantee a port's prosperity and it becomes increasingly difficult to define the limits of a port's natural hinterland. Port traffic is therefore more likely to be determined by cost and service advantages.

Market concentration

While the development of transport technology has eroded the element of local port monopoly through its effects on inland transport costs, it has at the same time enhanced the likelihood of port natural monopoly. Before World War Two most vessels were general purpose cargo ships. After World War Two specialised ships began to appear: firstly giant oil tankers developed, followed by ore carriers, grain carriers and OBO vessels. In the 1960s and 1970s a wide variety of new types of vessels have appeared to signify a new era of cargo transportation: container vessels, Ro-Ro vessels, LASH vessels, LGP tankers, new types of ferry boats and ships specialising in particular products such as certain chemicals, automobiles and locomotives. The rapid change of maritime transport technology, combined with rapidly rising labour costs in advanced economies in the post-war period brought a demand for more productive cargo handling techniques. The response was the adoption of specialised container and bulk handling facilities, which can be seen as a revolution in port technology. In contrast to the conventional port technology which is notoriously labour intensive, the modern technology of cargo handling is capital intensive. It is believed that there are substantial economies of scale in port operation. Moreover, substantial scale economies are also believed to exist in modern maritime technology. Modern cargo vessels are larger in size and more expensive in terms of the opportunity cost of staying at ports. Thus the best interests of both ship and port operators require traffic concentration in fewer and larger ports. This suggests that we should expect to observe a tendency for port markets to become more highly concentrated.

However, despite the above, it can be argued that the net impact of technological development on port market concentration is unclear. Consider Fig 2.1-2, which depicts a conventional U-shaped long-run average cost curve, LRAC1, for a typical port in a particular port market. In the long-run competitive equilibrium, the port will be of optimal size q_1 and there is a corresponding market demand Q_1. The market share of the typical port is q_1/Q_1. Owing to technological development, the long-run average cost is shifted downwards to LRAC2, which increases the optimal scale to q_2 and market size to Q_2. It follows that market concentration will increase only when the growth in market size Q_2-Q_1 is less than the increase in optimal port scale (q_2-q_1) (Clarke, 1985, pp.28-31). But technological development has indeed enlarged the port market size at the same time as enlarging port size and the net impact of the two effects may go either way.

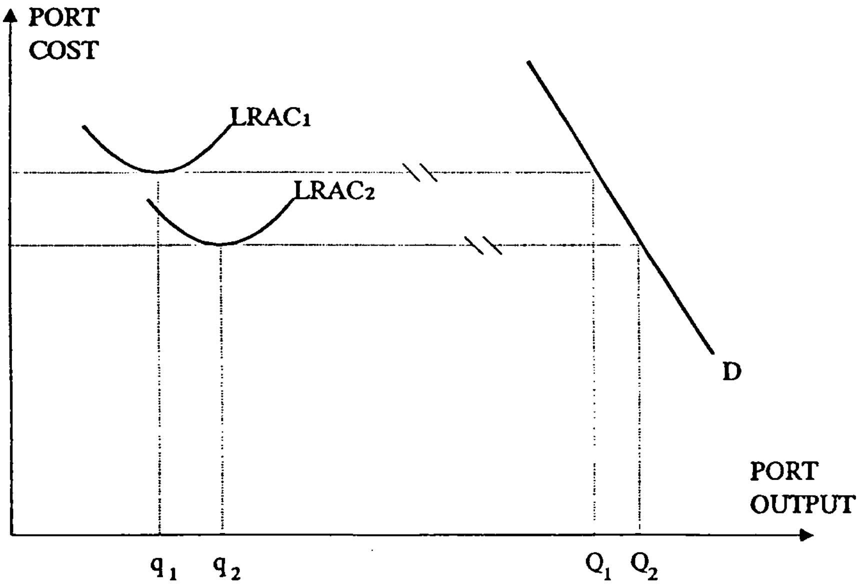

Fig 2.1-2 Market Concentration and Technological Development

Furthermore the extent to which economies of scale can be achieved from larger ports is questionable. In challenging the idea of a super port, Gilman (1980) argued that economies of scale in terminal operation are weak. For instance, for deep-sea trades where container dwell times are typically long, it is found that a wide spread container exchanges of 3000 to 6000 TEUs are indigestible in many terminals, and the increase of potential terminal throughput and the reduction of costs are difficult. The economies of ship size are also not as powerful as expected. Concentration of deep-sea ship itineraries is associated with a much higher cost of secondary distribution.

Earlier Bennathan and Walters (1979, pp.43-50) argued that the concentration of port traffic in a smaller number of ports increases inland transport costs, and after a certain level of concentration locational disadvantages may more than offset economies of scale derived from the concentration of port traffic. Thus there is a trade-off between economies of scale in operation and diseconomies in location.

Empirical evidence in Britain seems to support the view that economies of scale are not substantial enough to justify high traffic concentration. Port markets are better defined in terms of trade areas and cargo groups. Unfortunately the cargo classification adopted from 1981 onwards is different from that used before in official publications of port statistics, and there is thus no consistent data available to calculate the trend of market concentration for different trade areas and cargo groups. Shown in Table 2.1-1 are the 5-Ports concentration ratios (denoted by C_5) in Britain for bulk fuel and other traffic from 1965 to 1990 and for container and Ro-Ro traffic from 1971 to 1990, which are the shares of the total port traffic accounted for by the biggest five ports. Although they are calculated on the basis of aggregate data, they are probably sufficient to reflect the trend of market concentration for different trade areas and cargo groups.

Surprisingly there is no evidence to show a significant increase in port market concentration over the last 25 years. From 1965 to 1990 C_5 increased by only 6% for bulk fuel but declined by as much as 19% for traffic other than bulk fuel. For container and ro–ro traffic, where scale economies are supposed to be the most pronounced with the new technologies, C_5 has been fairly stable within the range from 45% to 50%. The corresponding figures calculated for 12 port regions (not shown) also indicate a stable trend in market concentrations. Therefore, as far as the UK is concerned, there has been no significant trend of port traffic concentration over the last 25 years.

Table 2.1–1 5–Port Traffic Concentration Ratio C_5 in the UK 1965–1990

Years	1965	1970	1975	1980	1985	1990	Change
Bulk Fuel	53%	49%	46%	49%	54%	59%	+6%
Others	57%	49%	44%	38%	38%	38%	-19%
Years	1971	1975	1979	1983	1987	1991	
Cont/Ro-Ro	45%	45%	47%	49%	52%	42%	-3%

Note: Cont/Ro–Ro: Container and Ro–on and Ro–off cargo.
Source: *Port Statistics* 1990.

Countervailing power of port users

If modern maritime transport technology had indeed exhibited substantial economies of scale, this would have implied not only an impetus to market concentration from the supply side (fewer and bigger ports) but also a tendence for market concentration from the demand side (fewer and bigger shipping companies).

Galbraith (1952) argued, *inter alia*, that in modern oligopolistic industries, the main force compelling sellers to conform to consumer wants and to hold price near cost is not competition but the contervailing power exercised by strong buyers. An important influence here is the theory of countervailing power. Briefly, a concentration of power on the demand side will invoke a balancing concentration of power on the supply side. When a few large shipping companies bargain with a few large terminal operators, it is likely to be more difficult for terminal operators to hold price above cost, all else equal.

The implications of buyers' power are complicated. On the one hand strong buyers tend to have some monopsony power over sellers. On the other hand, strong buyers are also likely to have monopoly power in the market where they act as sellers. Ideally we would like buyers' power not to be so weak that buyers can bear on the pricing of sellers and at the same time not so strong that the same buyers face substantial price competition in their product and service market. Fortunately such buyers can be found in the port market. There are six logically possible market structure types involving power on the buyers' side, including a single buyer facing a single seller (bilateral monopoly), a single buyer facing many purely competitive sellers (pure monopsony), a few buyers facing a few sellers (bilateral oligopoly), a few buyers facing many sellers (oligopsony) and so on. Among the six main market structure types, bilateral oligopoly is the most promising in the sense that the buying firms possesses some monopsony power but not monopoly power. Port markets may provide a classical example of bilateral oligopoly where a few port oligopolists face a few shipping oligopolists.

Shipping companies with strong buyers' power restrain the power of port oligopolists in several ways. One is that terminal operators are prone to cut prices in order to land an unusually larger order, especially when they have excess capacity. Contracts in which shipping companies commit themselves to particular port terminals are large in quantity and long in duration. Shipping companies can exploit the weakness of stevedoring operators by dangling the temptation before each of them to encourage a break from the established tariff structure. An example of this tactic was found in the bargaining process of Sealand with Rotterdam and Antwerp in 1987 for a ten year contract from 1990.

Shipping companies with strong buyers' power also play off one port oligopolist against another to induce price concessions. In continental European ports, for instance, major shipping companies have a principal terminal ususally, but each also spreads its business around terminals in other ports so that it can threaten to shift, or actually shift, its distribution of orders in favour of terminal operators who offer more attractive terms.

The power of port users to induce price cuts is strongest when demand for port facilities and services is slack, so that ports have excess capacity that can be utilised profitably if an increased share of some major shipping companies' business can be captured by price cuts.

Contestability of port markets

There are alternative definitions of entry barriers which have been used in the literature. Demsetz (1982) and Brozen (1975) have sought to confine the idea of entry barriers to government-based restrictions on entry. Stigler (1968) focuses on asymmetries in demand and cost conditions between established firms and potential entrants. The definition of entry barriers, which is given by Bain (1968) and is most often used in industrial economics, centres on the extent to which established firms can elevate their selling prices above the minimum average costs of production. Entry barriers to port markets are probably high on all definitions. First of all there are government-based restrictions. Potential operators may be unable to engage in port business simply because the provision of port services is controlled by the port authority or an official license must be held. There are also geographical restrictions because suitable sites to build a port or land needed for storage areas are not available everywhere. Economic barriers to entry such as location superiority, absolute cost advantage enjoyed by established port firms and economies of scale are also present. The most formidable barrier, however, is probably due to the sunk cost of investment in port facilities which are highly specialised and they are either not re-saleable at all or re-saleable with a substantial loss compared to the purchase price. The contestability of port markets is thus hopelessly low.

With these considerations in mind it is interesting to note a policy suggestion by Goss (1987, pp.31-39) to encourage potential competition in port industries by making port markets contestable. Basically it is suggested that the port authority builds terminals for leasing out on a competitive basis, for a period long enough to enable the licensed operator to acquire the experience necessary for efficient operation and to secure an adequate return, but short enough to enable them to be aware of the possibility of losing the next alteration of leases if they do not behave properly. Under these circumstances the established operators would set their price level lower than the limit price so as not to attract competition for leases. When prices have to be low, the only way to increase profit is to improve productivity.

Port markets would then be contestable in the sense that everyone would be free to compete for the franchise in the form of an auction for the monopoly right actually to provide a particular port service (cargo handling, warehousing, towage, pilotage, etc.), rather than in the sense that potential entrants are free to come into the market to compete with established firms. The idea can be implemented by making purposive use of the structure of landlord ports or tool ports where investment in infrastructure or even superstructure is undertaken by port authorities and the amount of private investment in capital assets is limited. At one extreme all major port facilities and equipment could be leased from port authorities through contractual arrangements as well as the infrastructure.

There are reasons, however, to doubt that the franchise will be truly competitive. Although it is possible for investment decisions regarding the superstructure as well as the infrastructure to be left to public port authorities while competition is made for the operating franchise, it is argued that the operating franchise allows market forces to act only to a limited extent, and the divorce of investment and operating decisions can lead to an undesirable loss of coordination (Vickers and Yarrow, 1989, pp.110–115). The major change in world ports since World War Two has been specialisation. Common user quays were replaced by more specialised ones for handling of container and Ro–Ro, or dry bulk, or liquid bulk or conventional traffic or for multi–purpose use for particular shipping companies. On the one hand the business decision to commit to a particular cargo, or a particular type of vessel, or a particular terminal user tends to be obstructed or delayed by bureaucratic procedure if public port authorities are responsible for investment. On the other hand it is reasonable that he who gains the benefit of specialisation should take the investment risk of specialisation. For this reason in the continental European landlord ports there has been increased private investment in superstructure, while the investment domain of public authorities has been narrowed to the infrastructure. As long as private investments are needed, the sunk cost will place potential entrants at cost disadvantage. If winning the franchise is based on the maximum bid, established operators are more likely to succeed as compared with new entrants. Since their investment expenditure on capital assets is sunk, they have firmer commitment to the industry and are likely to be more determined to win the franchise. While potential entrants have the opportunity to invest elsewhere, their commitment to the industry is less firm. Established operators are thus willing to pay more for the franchise than potential operators. It is also reasonable to expect that potential operators are at a cost disadvantage, as compared with the incumbents in access to superior port technology as a result of experience, patented or secret processes and management expertise and skilled labour. Also there may be long-established customer loyalty to the existing operator.

If winning of the franchise is not based on the maximum rent to be paid, but is based on actual performance (as with the British TV franchises), there will be problems of administration and the idea loses part of its appeal.

There are also problems of asset handover, of contract specification and enforcement (Vickers and Yarrow, 1989, pp.110-115). When the entrant defeats the existing operator in the competition for the franchise, there is a tough problem of asset handover which involves considerable expense in negotiation and arbitration regarding the appropriate transfer price.

The most difficult problem is that it is probably impossible to specify explicit conditions in terms of the qualities and the charges of port services to be provided. But a contract without such conditions reduces the attractiveness of franchise as a form of potential competition. The duration of the lease is also a problem. Relatively short-term leases tend to produce effective and constant pressure of potential competition on the existing operator. The difficulties of contract specification and administration also suggest that the short-term contract has advantages because less future uncertainty needs to be taken into account. But short-term leases are likely to inhibit technical progress and discourage private investment as short-term operators tend to be near-sighted. At the time of specialisation the long-term contract for the use of specialised terminals by a particular user also makes short-term leases impossible. The building of brand loyalty for terminal operators also favours long term leases.

These are, of course, just conjectures. The franchising of port services based on contestability of port markets remains an attractive idea. This can be a form of port privatisation alternative to the British model. With this option, ports can preserve their public nature while public involvement in port business is reduced to the minimum level. Where there is indeed a case of natural monopoly in ports and the scope of actual port competition is really limited, policy makers with this option may be in a better position to deal with the dilemma of how to enjoy scale economies of port traffic concentration without suffering from monopolistic behaviour. The option merits further discussion and empirical study.

2.2 Principal–Agent Relationship under Alternative Forms of Port Ownership

The principal–agent problem arises from the diversity of objectives and asymmetry of information. The agent is supposed to act in the interests of the principal, but unfortunately the agent does not in general share the same objectives as the principal. In addition, the principal does not have full information about the circumstances and behaviour of the agent. Thus the principal has a problem to induce the agent to act in his interest and to monitor his behaviour and performance. The performance of the agent depends on the effectiveness of the monitoring system that governs the principal–agent relationship.

A change in port ownership alters the principal–agent relationship. In any event port management remains as the agent and normally consists of similar persons in terms of motivation, personality and managerial skill. What is changed by a change of ownership are the incentive structures imposed on the management, which implies two things in particular. First, there will be a change in the objectives of the principals (shareholders in the case of a private port, the local public in the case of a municipal port and the general public in the case of a trust port and a national port). Second there will be a change in the arrangements for monitoring the performance of port management. Differences in the objectives and in the monitoring arrangements may cause differences in performance.

Private ports

The principal in the case of a private port is the body of shareholders. Vickers and Yarrow (1989, pp.7–34) provide a detailed analysis of the principal–agent relationship between shareholders and management of private–sector companies in general. Their analysis should also apply to the case of private ports.

The objective of shareholders is assumed to be maximisation of the expected return from port assets, although, in general, shareholders will not be unanimous in their rankings of managerial policies. Port managers are assumed to be concerned with their own utility but can be induced to pursue profit by three groups of participants in capital markets:

(i) the port's shareholders, who seek contractual arrangements with port management that maximise their own payoffs;

(ii) other investors or their agents (e.g. management of other companies), who might take over or purchase the port and alter existing contractual arrangements;

(iii) the port's creditors, seeking managerial changes in the event of threatened or actual default.

Under competitive pressure in markets for port services profit-maximising port producers are unlikely to charge much above marginal costs and the pursuit of profit thus provides a vigorous and constant incentive to improve productive efficiency.

Nevertheless the proposition that the managers of private ports will always be effectively constrained to act in the best interest of shareholders is not uncritically acceptable.

As far as the monitoring system of shareholders is concerned, the main problem is associated with the dispersion of shareholders. When the ordinary share capital of a port is divided amongst many investors, the activity of specifying and enforcing managerial contracts confers external benefits on other shareholders so that the intensity of monitoring is lower than the optimal level. A shareholder, in order to impose his view, must investigate the performance of the port, the extent to which port management was responsible for poor performance, the extent to which port managers are able to rectify the failure. Because of information asymmetry, these efforts require substantial costs, as is also the case if an individual seeks to remove a management board member through the shareholder voting system. The enforcement costs incurred are often unlikely to justify the benefit which accrues to the individual shareholder.

The theoretical and empirical analysis of takeovers suggests a number of limitations to this form of capital market constraint on the performance of managements. One of the problems, for instance, is due to the relatively insignificant influence of shareholders on acquisition decisions, over which managers continue to have considerable discretion.

Regarding the effect of bankruptcy, there are at least two limitations on the strength of the incentives for internal efficiency. Firstly, when probability of bankruptcy is high managements tend to enjoy managerial discretion in the short run so that the incentives for the improvement of internal efficiency disappears. Secondly, the determination of the firm's debt level is frequently at the discretion of the management and hence the management can ease the constraint it faces.

For all these reasons, although the managers of private ports are concerned with meeting the requirements of shareholders and may be faced with threats of take-over and bankruptcy, they clearly have some discretion to pursue goals other than profit maximisation. More likely they may aim to maximise their own utilities subject to satisfying certain profit targets.

Public ports

Under this heading are covered trust ports, municipal and national ports. The most evident feature of the principal-agent relationship under public ownership is that the principals (voters) do not typically seek to maximise profits and the agents are not typically threatened by take-over and bankruptcy. However this need not imply that managerial incentive structures are weaker in public ports than in private ones. By managerial changes and profit-related bonuses government can induce management to perform efficiently. A potential advantage of government monitoring over private monitoring is that public ownership provides an instrument for correcting the failures associated with dispersed shareholdings and corporate control.

The problem in the case of national ports lies in the multiple levels in the public monitoring hierarchy, which involve three levels of the principal-agent relationship, including voting public and elected politicians, elected politicians and civil servants, civil servants and port management. Ports in the central-government sector fall into two categories. One consists of those which are administered directly by central governments: the other is those where the management function is entrusted to a separate administration service. National ports in Britain, including those which once existed (BTDB) and the only one left (BWB), belong to the second group. They were public corporations, like most other nationalised enterprises in Britain. Public corporations combine freedom for management from government's supervision of day-to-day operations with public control of the broader policies of the enterprises. Nevertheless, the public control hierarchy is highly vulnerable to goal displacement and excessive ministerial intervention.

The objectives laid down for public port management are often multiple, varied and unclear. A summary of some conceivable port management objectives, though not exhaustive, as given by Suykens (1986) is as follows:

--obtaining the maximum throughput with the existing capacity;
--maximising net profits of the port authority;
--operating port at least cost in real terms;
--striving for highest employment level in the port;
--securing national independence of the country's maritime transport;
--promoting regional economic growth;
--offering the shippers and receivers the highest possible quality of service in terms of transit speed of the goods, reduction of the amount of damage and pilferage etc.;
--optimising vessels' time in port;
--reaching financial autonomy of the port authority;
--minimising total cost of maritime transport;
--maximising return on capital investment;
--minimising required capital investment.

As Suykens argued manifold objectives reflect the great number of parties involved in a port, including national and local government, the chamber of commerce, trade unions, shipping lines, shippers as well as port operators. They all have an interest in determining port administration objectives, and try to impose their own influences in setting the objectives. Public ports are expected to pursue public interests. But public interests may well be in conflict. The benefits derived from the existence and development of ports differ across the population. The general public has an interest in the efficient provision of port facilities and services, for otherwise they will have to pay more than necessary for the use of ports in terms of either more tax or higher port tariffs. The local public living around the ports, however, tends to attach more importance on the prosperity of port economy. It is in their interest to have more jobs and more business and personal income generated by the port and port–related industries. As far as dock workers are concerned an improvement in efficiency may have an adverse effect on their welfare. For instance, registered dock workers are worse off following the abolition of the Dock Labour Scheme which protected them from casual employment. There are also conflicts between commerce and aesthetics, between economic advantages and social costs, between residential, recreational and commercial land use. Politicians are assumed to be concerned about their electoral benefits. Given the divergence in the public interest over ports, it is improbable that politicians will have a constant incentive, persistently induced by the general public, to administer national ports efficiently. The priority given to particular objectives, as a result of political struggle, is likely to keep changing. There is little reason for believing economic efficiency will always be given first priority in port management.

Since 1978, public corporations in Britain have been exhorted to maximise efficiency subject to a generally tight set of constraints of financial and production cost. In contrast to their counterparts in Continental Europe and the USA, public ports in Britain are unique in their financial independence. A series of financial objectives for UK ports is contained in a memorandum of the National Ports Council of 25 November 1975, and these suggest that each port authority should generate sufficient cash revenue each year to meet: 1) interest and any taxation and dividends to shareholders; 2) redemption of capital debt actually falling due in the financial year, and provision towards the redemption of capital debt falling due for repayment in future years; 3) 50 per cent of all capital expenditure; The annual consolidated surplus (before exceptional items, taxation and interest charged to revenue but after making full and proper provision for the depreciation out of revenue) should present a return on capital of not less than 10 per cent (Financial Objectives, 1978). The requirement that the port cover its costs provides a valuable administrative incentive to the port authority to control its costs and its expansion plans.

While managerial discretion can be reduced by tighter financial constraints, the problem of ministerial discretion remains. A necessary administrative feature of national ports is centralisation. Government tends to retain many key decisions such as investment, tariffs, and personnel at ministry level, or if not made directly by the ministry these decisions are often subject to ministerial approval. With excessive intervention national ports tend to suffer from a lack of energy and vigour and tend to be too bureaucratic, too inflexible to respond adequately and promptly to the market situation and to customer needs.

Given these fundamental weaknesses it is likely that the incentive structures imposed on national port managements are in general defective as compared with private ports, even though the capital market for corporate control is not perfect.

This conclusion, however, cannot automatically apply to the case of municipal and trust ports. Unlike national ports municipal ports are responsible to local authorities rather than to national government. As a result of decentralisation, there are two immediate effects on the public monitoring process. The first is the alleviation of the problem of information asymmetry. In general local governments tend to know more than the national government about the circumstances and performance of port management. This may make it easier for local government to design and enforce incentive schemes to induce ports to be managed properly. In general intervention by local government is likely to be better informed. Moreover, the administration of municipal ports may involve fewer levels of bureaucratic hierarchy. In some ports management is a department of the local authority. In others managing directors are members of local councils. Thus the gap between local government and port management is narrower. In consequence port management may suffer less from the inefficiency of red tape and tend to respond to a changing market situation more promptly and adequately.

Perhaps the most hopeful form of public port ownership is the public trust. The principal-agent relationship in the case of trust ports possesses two distinguishing features. One is the autonomous status of the agent. No one is entitled to intervene as long as trust ports act properly in accordance with statutory objectives laid down for them by parliament. The other is a simpler process of public monitoring. Because of their autonomous nature there is less scope for hierarchial and bureaucratic administration of port matters. The principal-agent relationships in national, municipal and trust ports are contrasted in Fig 2.2-1. Although the public monitoring hierarchy for a trust port looks the same as for a national port, the links between port management on the one hand and politicians and the Ministry on the other hand are indicated by the lines of dashes, meaning that trust ports are under no direct administration of either Parliament or the Ministry.

Given these desirable features trust ports have three potential advantages over municipal and national ports. Firstly, the management objectives of trust ports are statutory and there is no way that these objectives can be displaced by political objectives. Secondly trust ports are free from excessive intervention from government and enjoy almost the same degree of freedom as private ports. Thirdly trust ports are likely to suffer much less from the internal inefficiency of bureaucracy.

The core of the autonomous nature of trust ports is financial independence. This provides a managerial incentive to improve productive efficiency. Compared with the pursuit of profit by private ports, the requirement that the port recover its costs is a constraint rather than a objective. Port management may still have discretion to pursue their own benefits as long as the constraint is met. It may be argued that financial independence is thus not likely to generate as much incentive to improve productive efficiency as the objective of profit maximisation. But equally it can be argued that, because of imperfections in the capital market for corporate control, managers in private ports may also merely pursue the financial objective of satisfying shareholders.

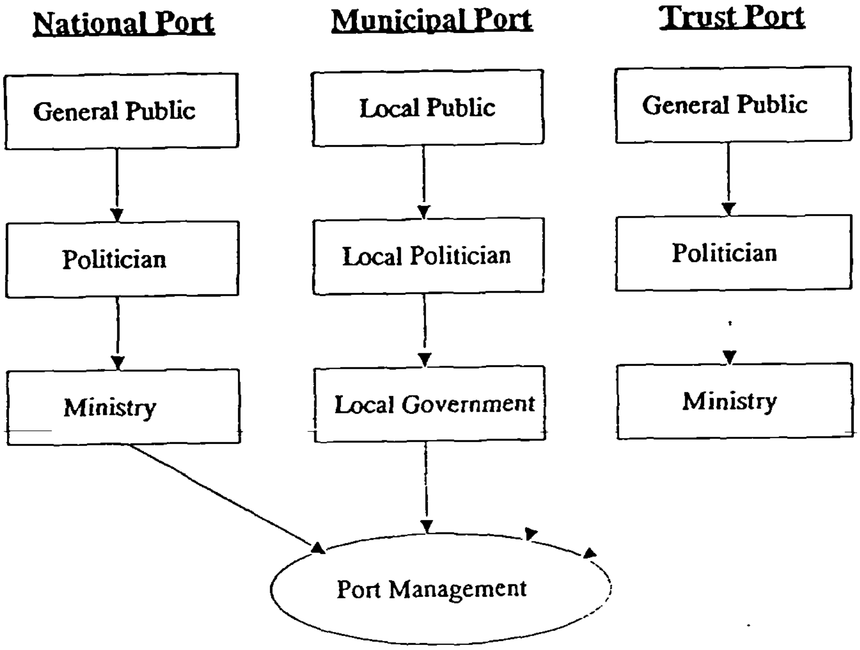

Fig 2.2-1 Alternative Public Monitoring Hierarchies

To summarise; public ports may suffer from deficiences of public monitoring hierarchies, goal displacement, lack of clarity in corporate objectives and operative responsibility, and excessive ministerial intervention in operational decisions. The deficiencies, however, are not unavoidable and in fact can be reduced when port administration is decentralised, as in the case of municipal ports, or independent from government as in the case of trust ports. On the other hand, the private monitoring system also suffers from imperfections. It is therefore not safe to conclude which monitoring system is generally more effective as far as the port industry is concerned. The corollary of this is that the efficiency gains of privatising ports under indirect public ownership because of the change in managerial incentive structures are likely to be small correspondingly.

2.3 Port Pricing and Investment Performance under Alternative Froms of Ownership

This issue has been treated in an important but neglected paper by Bobrovitch (1982). Based on a two-ports system model, Bobrovitch shows (a) the equivalence of centralised planning and decentralised maximisation of net social welfare; (b) the apparently suboptimal traffic allocation resulting from competition between profit maximising ports, but allocative inefficiency disappears when demand density is symmetric and the two ports are located symmetrically; (c) the port producers adopt the same investment rule regardless of whether they seek to minimise the costs of all participants in the system, or to maximise the net social benefit independently, or to maximise profitability. It is important to note that the result that private ports adopt the same investment rule as public ports does not mean that they will necessarily choose the same port capacity as public ports. Port capacity is a function of port output. If the allocation of traffic in a private-ports system is suboptimal, the port capacity chosen by private ports will be suboptimal as well. However, if the assumption of symmetric demand is acceptable, the effects of suboptimal traffic allocation and hence of suboptimal port capacity can be neglected.

If the immediate effect of the transfer of port ownership between central government sector, local government sector and the private sector is a change in the objectives of port management, Bobrovitch's model can be used to describe and compare pricing and investment behaviour and performance under the alterative forms of port ownership. But Bobrovitch's results can be questioned in two aspects. Firstly, Bobrovitch failed to show whether the port duopoly price level derived by him is a Nash equilibrium and whether or not such an equilibrium exists. Thus nothing can be said about the market performance of port duopoly relative to the publicly owned ports. Secondly, Bobrovitch confined himself to a partial analysis in which the cargo volume was taken as given in determining the optimal port capacity. Since the outcome of price competition in the Nash equilibrium depends on port capacity among other things, it is more plausible to assume that private ports will compete to choose the optimal port capacity to improve their position in the game of price competition. These two problems are tackled in what follows.

The discussion here is based on the following assumptions:

Assumption 1 The hinterland is a line segment of length *d*; port service is provided by two ports located at either end of the hinterland O and C as shown in Fig 2.3-1.

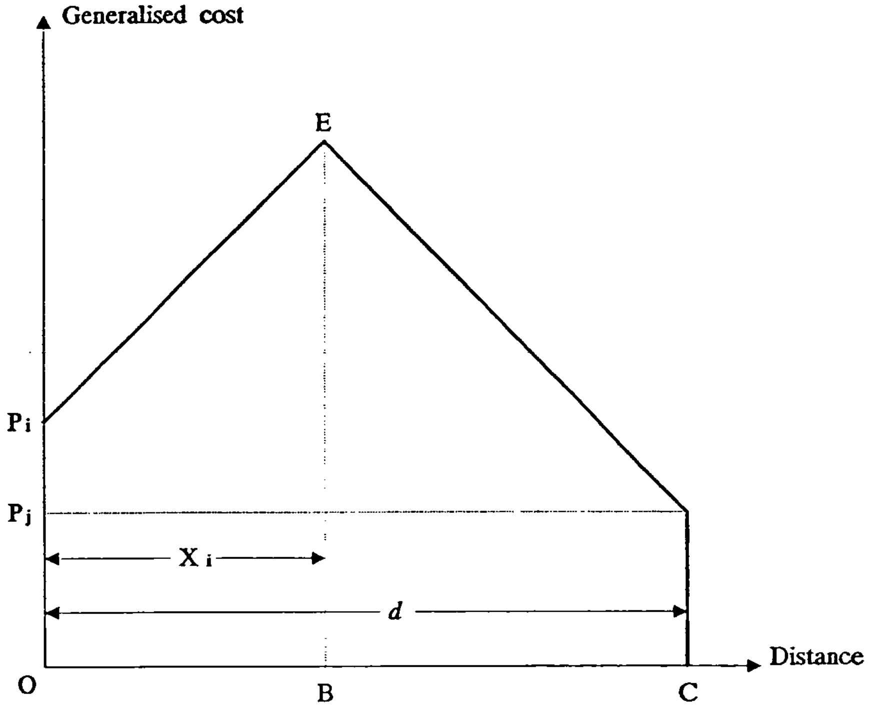

Fig 2.3-1 A Two-Port System

Assumption 2 The aggregate demand for port services is assumed to be absolutely inelastic regardless of changes in port charges and capacity. Without loss of generality, cargo is homogenous and evenly spread over the line segment. The density of cargo is one. Thus the aggregate demand is *d* as well.

The assumption of inelastic aggregate demand for port services is quite reasonable, since the proportion of port cost in the final product value is insignificant and port customers in aggregate are unlikely to be very sensitive to changes in port price. In addition, the assumption of uniform traffic distribution implies symmetric demand.

Assumption 3 Each port charges a uniform price. Ship time cost at port per unit of cargo is assumed linear in the port occupancy rate. Inland transport cost per mile for each unit of cargo is also linear in distance. Thus generalised transport cost per unit of cargo incurred by a marginal port user at a distance X_i from port i (i=1,2) is given by

$$T_i = P_i + a\frac{X_i}{K_i} + tX_i \tag{2.3-1}$$

Where P_i = port i's charge;

X_i = the length of port i's market; Given *Assumption 2*, X_i also represents port i's cargo volume;

K_i = port i's capacity;

X_i/K_i = port occupancy rate;

a = average opportunity cost of ship time in port per unit of cargo when port occupancy rate is 100%

t = constant inland transport cost per mile per unit of cargo.

Three points about *Assumption 3* need to be explained. First, the work of Singer (1937) and Hoover (1937), which was subsequently followed up by Greenhut (1975) and Beckman (1976), suggests that a profit-maximising spatial monopolist has an incentive and is able to adopt a policy of price discrimination by which he charges buyers a variable proportion of transport costs. The same applies to a profit-maximising port monopolist, and in many ports customers are in fact charged against their cargo origins and destinations. Here, however, consider only the simple case where ports charge a uniform price. Second, it may not be realistic to assume that average ship time cost $a(X_i/K_i)$ is linear in the port occupancy rate (X_i/K_i). In practice, this will tend to rise rather rapidly as port throughput approaches full capacity. But a non-linear average ship time cost will increase the algebraic complexity without yielding much further insight into the problem. Third, it is implicitly assumed either that ship operators and cargo owners are the same entities or that competitive ship operators will include port charges and ship delay costs in their rates so that cargo owners bear generalised transport costs in full.

Assumption 4 Production cost in port equals $c_iX_i+rK_i$, where c_i is the constant marginal cost in port i and r is the constant cost of capital per unit of capacity, which is identical in both ports.

Assumption 5 Port capital is divisible.

Assumption 6 Three options are available as regards the industrial organisation of the two-ports system. One option is equivalent to nationalising the two ports and putting them under a centralised administration. The objective of the central ports authority, be it the Ministry of Transport or a separate administrative service responsible to the Ministry, would be to maximise the social welfare of all the participants in the system. Given inelastic demand, this is equivalent to minimising the total costs of all the participants in the system. Under the second option, port administration is decentralised and each port is owned and administered by an independent public trust or a local authority. Each independent port authority is expected to maximise the social welfare of port producers and customers within the physical boundary of its port. The third option is to privatise the public ports. The managements of private ports are assumed to maximise profits. We also suppose that competition policy prevents one port from being merged or taken over by another so that the private-ports system remains a duopoly.

Assumption 7 Private ports engage in quantity-setting competition, in which ports decide how much cargo volume to handle and let the market decide the price at which port service is provided. Each private port acts in the belief that its rival will take the situation as given (i.e. a Cournot–like assumption).

This assumption needs explaining. First, we usually think of the distinction between quantity–setting (Cournot) and price–setting (Bertrand) behaviour as determined by the technology: how quickly can a firm alter the rate of output? Kreps and Scheinkman (1983) take a different approach and view the difference of the two types of competition as depending on whether production capacity is constrained or not. The distinction between quantity–setting and price–setting can be made in the port sector from both approaches. Port operators of common user terminals are unable to predict ship arrivals accurately when they decide to build terminals. They have to set production schedules in advance and cannot alter production capacity in the short run once the terminal is built. Thus competition between common user terminal operators is likely to be of the quantity–setting type. In specialised terminals, by contrast, long term contracts between port operators and shipping companies are made for the exclusive use of terminals before the commitment of either side to the specialised services. Port competition in this circumstance is likely to be of the price–setting type. However, even in common user terminals, price undercutting is possible when the existing terminal capacity is in excess of demand. Therefore it appears that the type of port competition depends *Ex–ante* (before terminals are built or re–developed) on the technology and *Ex–post* (once terminals are built and re–developed) on production capacity. In the following discussion attention will be confined to the quantity–setting type of port competition.

Second, the Cournot–like behavioural assumption in this quantity–setting port oligopoly model implies zero–price and non–zero–quantity conjectures. Since aggregate demand is fixed, there can be only two cases of conjectural variation: either the change in one port's cargo volume is fully absorbed by the opposite change in the other port's cargo volume (non–zero–quantity conjecture), or the change in one port's cargo volume is impossible simply because the other port refuses to change its cargo volume (zero–quantity conjecture). In contrast to general oligopoly models, the zero-quantity conjecture in this model is a belief that the rival port will be very aggressive. To prevent one port from changing its cargo volume, the rival port must change its price accordingly (non-zero-price conjecture). But if the rival port takes the situation as given, it must keep its price unchanged (zero-price conjecture).

Although the aggregate demand is absolutely inelastic, demand for an individual port is elastic as port users can divert their traffic from one port to the other. Obviously port users will choose the port with lower combined transport costs per unit of cargo. The allocation of the total traffic *d* between the two ports will not be in equilibrium until the following condition is satisfied:

$$(2.3\text{-}2) \qquad P_1 + a\frac{X_1}{K_1} + tX_1 = P_2 + a\frac{d-X_1}{K_2} + t(d-X_1)$$

One can derive the demand for port i from Eq(2.3-2)

$$(2.3\text{-}3) \qquad X_i = \frac{P_j - P_i + S_j d}{S_i + S_j}$$

where $S_i = t + a/K_i$; $i,j=1,2$; $i \neq j$.

Or the inverse demand function in terms of port charges

$$(2.3\text{-}4) \qquad P_i = P_j + S_j d - (S_i + S_j)X_i$$

$$(i,j=1,2;\ i \neq j)$$

In public policy analysis perfect competition as a welfare ideal is often taken as a benchmark case to evaluate the performance of alternative market structures. But the perfect competition model requires an assumption of no externalities in production and consumption. In a congestion-prone system like ports we cannot declare that external effects are of no importance. In the following analysis the outcome of centralised pricing and investment decision aiming to minimise the total costs of all participants in the system is taken as the benchmark case to evaluate the performance of decentralised public ownership and private ownership. Here we assume that administrative deficiency of central planning is of no importance, since we concern the optimising behaviour only.

Proposition 1 A centralised and a decentralised publicly owned two-port system are equivalent in their optimal solutions to pricing and investment problems:

(i) the optimal port price is determined by

(2.3-5) $P_i^* = c_i + a(X_i/K_i) \quad i=1,2;$

(ii) the optimal port capacity in both systems will be determined by

(2.3-6) $K_i^* = X_i\sqrt{(a/r)} \quad i,=1,2.$

The mathematical formulation of and solution to the centralised and decentralised optimisation problems and the proof of ***Proposition 1*** are given in Appendix 2.3-1 and 2.3-2.

The port pricing policy adopted in centralised and decentralised public ports as indicated in Eq(2.3-5) is based on a marginal cost and congestion pricing rule. c_i is marginal port producer's costs. aX_i/K_i is additional ship time costs incurred by all ships together as a consequence of the entrance of a marginal ship. It is shown in Appendix 2.3-1 that marginal ship time cost is given by $2aX_i/K_i$ and average ship time cost is given by aX_i/K_i. The operator of the marginal ship will take account of average rather than marginal ship time cost after its entry when he calculates the expected profitability of the service. Thus in the case where ship time costs are linear in the utilisation rate of port capacity the cost taken into account in private decisions is only half the cost incurred by society. The central port planner who seeks to minimise the total costs of all participants in the system, and the decentralised port authorities which seek to maximise the net social benefit in the physical boundary of their ports, will charge port customers the divergence between marginal ship time cost and average ship time cost, i.e. aX_i/K_i.

The marginal cost and congestion pricing ensure optimal allocation of traffic between different ports and different seasons. The topic of port congestion pricing is discussed more fully in Vanags (1977) and Bennathan and Walters (1979).

The optimal port capacity K_i^* as indicated in Eq(2.3-6) in both systems is positively related to the opportunity costs of ship time a and negatively related to the opportunity cost of port capital r. Due to the fact that port services are not storable, there is a problem of reconciling capacity with fluctuating demand. On the one hand, more capacity would imply lower ship time in port but higher costs of port construction. On the other hand, if less capacity were constructed, lower costs of port construction would be incurred, but ship time costs would rise. The optimal port capacity in the centralised and decentralised optimisation is determined by balancing the costs from both the port producers' and the customers' side.

Proposition 2 The optimal solution to pricing and investment problems in the privatised two-port system is different from the social optimum obtained in centralised decision-making. Particularly, if the two ports are identical in cost and capacity,

(i) the port duopoly price in the Nash equilibrium will exceed the socially optimal level;

(ii) the port duopolists will under-invest when they agree on market share and over-invest when they do not, as compared with the social optimum.

First of all let us identify the Nash equilibrium of the port duopoly in price and output. It is important to note that in the Hotelling model no Nash equilibrium exists when two firms compete on both price and location. When location is fixed and two firms are sufficiently far from each other a Nash equilibrium in price exists (Graitson, 1982). Given that port location is immobile and the two ports locate on each end of the line segment, there will be a Nash equilibrium in price. As shown in Appendix A2.3-3 the profit-maximising cargo volume based on zero-price and non-zero-quantity conjecture is given by

$$X_i = \frac{P_j + S_j d - c_i}{2(S_i+S_j)} \qquad (2.3\text{-}7)$$

$$(i,j=1,2;\ i\neq j)$$

and the implied port price will be

$$P_i = (1/2)(P_j + S_j d + c_i) \qquad (2.3\text{-}8)$$

$$(i,j=1,2,\ i\neq j)$$

The throughput each port will choose depends upon what it thinks the port price will be in the other port. In general the zero-price and non-zero-quantity conjectures are inconsistent. With the aggregate demand d, port i's throughput must be d-X_j if port j picks up its throughput as X_j. But when X_j is the profit-maximising throughput of port j, d-Xj need not be the profit-maximising throughput of port i. The converse is true as well. The port duopoly approaches equilibrium only when the sum of profit-maximising throughputs of the two ports is equal to d exactly, i.e.,

$$X_i + X_j = d \qquad (2.3\text{-}9)$$

or

$$\frac{P_j + S_j d - c_i + P_i + S_i d - c_j}{2(S_i+S_j)} = d \qquad (2.3\text{-}10)$$

Substituting Eq(2.3-8) into Eq(2.3-10) and rearranging gives

$$P_i = (1/3)(S_i d + 2S_j d + 2c_i + c_j) \qquad (2.3\text{-}11)$$

$$(i,j=1,2,\ i\neq j)$$

Substituting P_i in Eq(2.3–11) into Eq(2.3–7) gives

$$(2.3\text{-}12) \qquad X_i = \frac{3td+(a/K_i)d+(2a/K_j)d+c_j-c_i}{3(2t+a/K_i+a/K_j)}$$

$$(i,j=1,2,\ i\neq j)$$

Crucially, as X_i in Eq(2.3–12) satisfies $X_1+X_2=d$, X_1 is port 1's optimal choice given X_2 as port 2's choice, and X_2 is port 2's optimal choice given X_1 as port 1's choice, (X_1, X_2) determined by Eq(2.3–12) and (P_1, P_2) determined by Eq(2.3–11) are the port duopoly output and price in Nash equilibrium.

When the two ports are identical in cost and capacity, i.e. $c_i=c_j$ and $K_i=K_j$, the pair of prices and outputs in Nash–equilibrium reduces to

$$(2.3\text{-}13) \qquad P_i = c + (ad/K) + td$$

$$(2.3\text{-}14) \qquad X_i = d/2$$

From ***Proposition 1*** it is easy to see that $P_i^*=c+(ad/2K)$ and $X_i^*=d/2$ is the social optimum when the two ports are identical in cost and capacity. With the term (ad/K) included in port charges, port duopoly in effect internalises the external effect of port congestion. But, as compared with the social optimum achieved in centralised and decentralised public ports, the port duopoly overcharges port users by the amount of $(ad/2K)+td$. The market power of the port duopoly stems from both the cost of inland transport (td) and the scarcity of port capacity $(ad/2K)$. The economic effect of overcharging is income redistribution from port customers to producers. With inelastic aggregate demand overcharging port price does not lead to a deterioration in efficiency of resource allocation between ports and other sectors. According to Eq(2.3–14), the duopoly level of output is equal to the social optimum, provided that the two ports are identical in cost and capacity and that demand is symmetric (as implied by ***Assumption 2***). Thus there will be no distortion in traffic allocation either, as long as ports are identical and demand is symmetric. Intuitively this is so because traffic allocation depends on the relative rather than the absolute price level of two ports. The optimal pattern of traffic allocation divides the hinterland equally and this will not be changed as long as the two identical ports charge the same level. An important corollary of this is that the distortion in traffic allocation may well be greater with *different* objectives of port pricing as compared with identical objectives of port pricing. Thus mixed port ownership in this country might be undesirable from a traffic allocation point of view.

Now consider investment performance of port duopoly. Bobrovitch derived the profit-maximising capacity by setting $\partial \Pi_i/\partial K_i=0$ (where Π_i is the profit function in Eq(A2.3-3-1) and he then concluded that the investment rule is the same as Eq((2.3-6). It was assumed that port oligoplists would treat the pricing and investment decisions separately. When they chose the profit-maximising output they would take the capacity as given. And when they chose the profit-maximising capacity they would take the market share as given. This partial analysis certainly fails to reflect real features of oligopolistic competition in port sectors. It would be more plausible to view port competition as a set of interrelated games. Since the outcome of price games is predetermined largely by the outcome of investment games, port duopolists would make every effort to improve their position in the price games through investment competition. In our analysis equilibrium price and capacity is determined in the following manner: taking port capacity as fixed, Nash equilibrium price is first sought, then profits are expressed as a function of capacity alone and the investment rule of port duopolists is sought. Assume that initially the two ports are identical in capacity and cost and that they take turns to invest so the two ports remain identical throughout the game of capacity competition. Recalling P_i in Eq(2.3-13) and X_i in Eq(2.3-14), the profit in Nash equilibrium is given by

$$(2.3\text{-}15) \qquad \begin{aligned} \Pi_i &= (P_i - c_i)X_i - rK \\ &= (c + td + ad/K - c)d/2 - rK \\ &= (1/2)(t + a/K)d^2 - rK \end{aligned}$$

Apparently the port duopolists have an incentive to under-invest as long as they agree on maintaining the existing market share in Nash equilibrium, since capacity expansion erodes profitability:

$$(2.3\text{-}16) \qquad \frac{\partial \Pi_i}{\partial K_i} = -\frac{ad^2}{2K_i^2} - r < 0$$

As already noted, the degree of monopoly power is partly due to the scarcity of port capacity. Given cargo volume port duopolists will be better able to raise port charges if port capacity is lower in relation to demand. But each port duopolist also understands that in general its market share in Nash equilibrium as expressed in Eq(2.3-12) is a function of its capacity and its rival's capacity among other things, and that

$$(2.3\text{-}17) \qquad \frac{\partial X_i}{\partial K_i} = \frac{3adt + 3a^2d/K_j}{(6tK_i+3a+3aK_i/K_j)^2} > 0$$

given identical marginal cost. It does not have to maintain its market share. Rather each port will be able to enlarge its market share by expanding its capacity. But capacity expansion in one port will then provoke competition on capacity from its rival port in order to defend its market share, because

$$(2.3\text{-}18) \qquad \frac{\partial X_i}{\partial K_j} = \frac{-3adt - 3a^2d/K_j}{(6tK_i+3a+3aK_i/K_j)^2} < 0$$

Although each port duopolist knows that

$$(2.3\text{-}19) \qquad \frac{\partial P_i}{\partial K_i} = -\frac{ad}{3K_iK_i} < 0$$

which implies that competition on capacity will erode profitability, the situation will get even worse if the rival port siezes the expansion opportunity, because

$$(2.3\text{-}20) \qquad \frac{\partial P_i}{\partial K_j} = -\frac{2ad}{3K_iK_i} < \frac{\partial P_i}{\partial K_i}$$

Port competition on capacity will not stop until the expected profit is zero. Recall that the profit in Nash–equilibrium when the two ports are identical in capacity and cost can be written as Eq(2.3–15). The equilibrium capacity denoted by K_i' is such that

$$(2.3\text{-}21) \qquad \Pi_i(K_i') = 0$$

Substituting the socially optimal port capacity K_i^* into Π_i we have

$$(2.3\text{-}22) \qquad \Pi_i(K_i^*) = (1/2)(t + a/K_i^*)d^2 - rK_i^*$$

$$= (1/2)(td^2 + rd\surd(a/r)) > 0$$

Since

$$(2.3\text{-}23) \qquad \Pi_i(Ki^*) > \Pi_i(K_i') = 0$$

and

(2.3-24) $\partial\Pi_i/\partial K_i < 0$

it is obvious that the equilibrium capacity when the port duopolists disagree on market share is larger than the optimal level:

(2.3-25) $K_i' > K_i^*$

Therefore in either case the duopoly level of port capacity is different from the social optimum. The departure from the optimal level of capacity causes a more serious welfare loss than the departure from the optimal level of price. Investment efficiency rather than allocative efficiency should be the focus of applied welfare analysis in port economics.

Appendix 2.3-1

Optimisation in a Centralised Publicly Owned Two-port System

The optimisation problem of the central planner is how to allocate total traffic d between the two ports in order to minimise the costs of all participants in the system, i.e.

$$\text{(A2.3-1-1)} \quad \text{Min} \sum_{i=1}^{2} TC_i = \Sigma[(1/2)tX_i^2 + a(X_i^2/K_i) + c_iX_i + rK_i]$$

$$\text{Subject to} \quad \sum_{i=1}^{2} X_i = d$$

where TC_i (i=1,2) is generalised transport costs in port i, including inland transport cost, ship time cost and port operating and capital cost. Recall that the term tX_i is unit inland transport cost for the marginal user at a distance X_i from port i. Given linear inland transport costs in distance, average inland transport cost for users at port i is $(1/2)tX_i$. Note that, under the uniform traffic density assumption (*Assumption 2*), X_i is equal to port i's traffic as well. Thus total inland transport costs for all users in port i is $(1/2)tX_iX_i$. Under *Assumption 3* $a(X_i/K_i)$ is unit ship time costs in port i, hence $a(X_i/K_i)X_i$ is total ship time costs for all users in port i. Given *Assumption 4* c_iX_i is operating costs and rK_i capital costs of port i.

Noting that $X_j=d-X_i$, minimum costs are given by setting $\partial\Sigma TC_i/\partial X_i=0$ and $\partial\Sigma TC_i/\partial K_i=0$ from which one obtains

$$\text{(A2.3-1-2)} \quad tX_i - t(d-X_i) + 2a(X_i/K_i) - 2a(d-X_i)/K_j + c_i - c_j = 0$$

$$(i,j=1,2;\ i\neq j)$$

and

$$\text{(A2.3-1-3)} \quad -a(X_i^2/K_i) + r = 0$$

$$(i,j=1,2;\ i\neq j)$$

Solving Eq(A2.3-1-2) for X_i we obtain the optimal throughput in port i, i.e.

$$(A2.3\text{-}1\text{-}4) \qquad X_i = \frac{dt + 2ad/K_j + c_j - c_i}{2(t + a/K_i + a/K_j)} \qquad (i,j=1,2;\ i \neq j)$$

Rearranging Eq(A2.3-1-2) one obtains

$$(A2.3\text{-}1\text{-}5) \qquad tX_i + aX_i/K_i + aX_i/K_i + c_i = tXj + aX_j/K_j + aX_j/K_j + c_j \qquad (i,j=1,2;\ i \neq j)$$

Comparing Eq(A2.3-1-5) with Eq(2.3-2) it is evident that the optimal price is given by

$$(A2.3\text{-}1\text{-}6) \qquad P_i^* = c_i + a(X_i/K_i) \qquad (i = 1,2)$$

The solution for K_i in Eq(A2.3-1-3) is the optimal capacity of port i (i=1,2), i.e.

$$(A2.3\text{-}1\text{-}7) \qquad K_i^* = X_i\sqrt{(a/r)} \qquad (i = 1,2)$$

Assuming that the two ports are identical so that $c_1=c_2=c$ and $K_1=K_2=K$, the least-cost pattern of port traffic allocation determined in Eq(A2.3-1-4) reduces to $X_1^*=X_2^*=d/2$. The optimal port capacity in (A2.3-1-7) is then given by $K_1^*=K_2^*=(d/2)\sqrt{(a/r)}$.

Appendix 2.3–2

Optimisation in a Decentralised Publicly Owned Two–port System

The real costs, denoted by θ_i, incurred by customers in port i include port charges P_i and average ship time costs $a(X_i/K_i)$. From Eq(2.3–2) one can derive the inverse demand function for port i in terms of the real costs, which indicate the willingness to pay by port users in port i, i.e.

$$(A2.3\text{-}2\text{-}1) \qquad \begin{aligned} \theta_i(X_i) &= P_i + a(X_i/K_i) \\ &= P_j + a(d-X_i)/K_j + t(d-X_i) - tX_i \\ &\quad (i,j=1,2;\ i \neq j) \end{aligned}$$

Following Bobrovitch, the net social welfare function that an independent port authority seeks to maximise is defined as the difference between social benefit derived from port i's services and social costs incurred by port i's producers and customers, i.e.

$$(A2.3\text{-}2\text{-}2) \qquad WF = \int_0^{X_i} \theta_i(Z)dZ - [a(X_i^2/K_i) + c_i X_i + rK_i]$$

$$(i,j=1,2;\ i \neq j)$$

Optimum WF is given by $\partial WF/\partial Xi = 0$ and $\partial WF/\partial Ki = 0$ from which one obtains

$$(A2.3\text{-}2\text{-}3) \qquad \theta_i(X_i) - 2aX_i/K_i - c_i = 0 \qquad (i=1,2)$$

and

$$(A2.3\text{-}2\text{-}4) \qquad -aX_i^2/K_i^2 + r = 0 \qquad (i=1,2)$$

Since $\theta_i = P_i + a(X_i/K_i)$, Eq(A2.3–2–3) implies that the optimal port charging level in decentralised public ports is given by

$$(A2.3\text{-}2\text{-}5) \qquad P_i = c_i + aX_i/K_i \qquad (i=1,2)$$

which is identical to the socially optimal level of port charges obtained in centralised public ports P_i^* determined in Eq(A2.3–1–6).

Eq(A2.3–2–4) implies that the optimal port capacity in decentralised planning is given by

$$(A2.3\text{-}2\text{-}6) \qquad K_i = X_i \surd(a/r) \qquad (i=1,2)$$

which is also identical to the social optimum obtained in centralised planning K_i^* determined in Eq(A2.3–1–7).

Appendix 2.3-3

Profit-maximisation in a Privately Owned Two-port System

Recalling the inverse demand function in terms of port price expressed in Eq(2.2-4), the profit function for port i is then given by

(A2.3-3-1)
$$\Pi_i = [P_j + S_j d - (S_i+S_j)X_i - c_i]X_i - rK_i$$
$$(i,j=1,2;\ i\neq j)$$

Maximum profits are given by setting $\partial\Pi_i/\partial X_i=0$. Assuming zero-price and non-zero-quantity conjectures, i.e. $\partial P_j/\partial P_i=0$, the profit-maximising throughput derived from the normal condition is given by

(A2.3-3-2)
$$X_i = \frac{P_j + S_j d - c_i}{2(S_i+S_j)}$$
$$(i,j=1,2;\ i\neq j)$$

Substituting X_i' into Eq(2.3-4) the implied port price will be

(A2.3-3-3)
$$P_i = {}^1/_2(P_j + S_j d + ci)$$
$$(i,j=1,2;\ i\neq j).$$

Chapter 3

Productive Efficiency of British Ports Relative to a Deterministic Frontier

This chapter and the next two involve estimating productive efficiency for British ports. In this chapter efficiency is measured against a deterministic reference technology, on the assumption that the entire deviation of an observation from the technology is attributed to inefficiency. Both parametric and non-parametric approaches are available to estimate the deterministic technology against which efficiency is measured. Since the parametric (deterministic) approach may impose an unwarranted structure on the production technology, the more flexible non-parametric approach was chosen, which enables us to explore systematically the various ways that a port producer might depart from overall productive efficiency relative to a piecewise-linear reference technology.

The chapter begins, in section 3.1, with a brief outline of the notion of a frontier function and the computational framework set up by Farrell (1957). The meaning of inefficiency relative to the production frontier is also discussed. Section 3.2 shows how the simple framework initiated by Farrell has been extended and developed into more meaningful and less restrictive non-parametric constructions. This section also provides a background for the development of parametric (stochastic) models in the next chapter. Given the non-parametric constructions outlined in section 3.2, the linear programming models used to calculate various notions of productive efficiency are set up in Section 3.3 and applied to British ports in Section 3.5. It is found that there has been substantial variation of productive efficiency in the industry and that X-inefficiency, technical inefficiency and scale inefficiency have been the important components of productive inefficiency.

3.1 Frontier Production Function

The textbook definition of a production function holds that it gives the maximum possible output which can be produced from a given quantity of a set of inputs. The word frontier may meaningfully be applied in this case because the function sets a limit to the range of possible observations. One may observe points below the production function frontier but no points can lie above the production frontier. The measurement of inefficiency has been the main motivation for the study of frontiers. As a matter of fact a departure from the frontier can be constructed as an index of inefficiency for the firm concerned. In early work, however, only average production functions have been estimated, since a linear regression model was postulated for the underlying technology. A crucial assumption here is that the mean of the disturbance term is zero. In other words discrepancies of actual output values from the expected output value are not attributed to any one-sided error such as inefficiency. Rather they are assumed to be symmetric, as a result of unspecified influences, randomness in human response and measurement errors, and will average out at zero. One cannot derive any meaningful efficiency measures from such an average production function.

The beginning point for any discussion of frontiers and the meaningful measurement of efficiency is the work of Farrell (1957), who provided definitions and a computable framework for productive inefficiency, which was decomposed into technical inefficiency and price inefficiency. Consider a port production activity involving two factors of input: labour X_1 and capital X_2, and producing a single output Y. Assume that the most efficient production technology currently available is represented by $Y=f(X_1,X_2)$. Also assume that the technology is subject to constant returns to scale, so that the frontier production function can be written as $1=f(X_1/Y,X_2/Y)$, i.e. the unit isoquant SS' as illustrated in Fig 3.1-1. The line PP' is the current isocost line (minimum cost of producing one unit of output). The crosses denote observable input coefficients for the ports in the industry. Let A be a specific port firm. Given the best technology currently available and the factor ratio of A, the most efficient production activity should take place at B. The Farrell measure of technical efficiency is then defined by the ratio of OB/OA. Given current factor prices, however, even B is not the most efficient (the least cost or the most profitable point) because of its non-optimal factor ratio. Hence, the observed port firm A is also price inefficient. The corresponding point of minimum cost is D and the Farrell measure of price efficiency for A is defined by the ratio of OC/OB. The measure of overall productive efficiency for A is then computed as the product of the technical efficiency measure and the price efficiency measure and is equal to OC/OA.

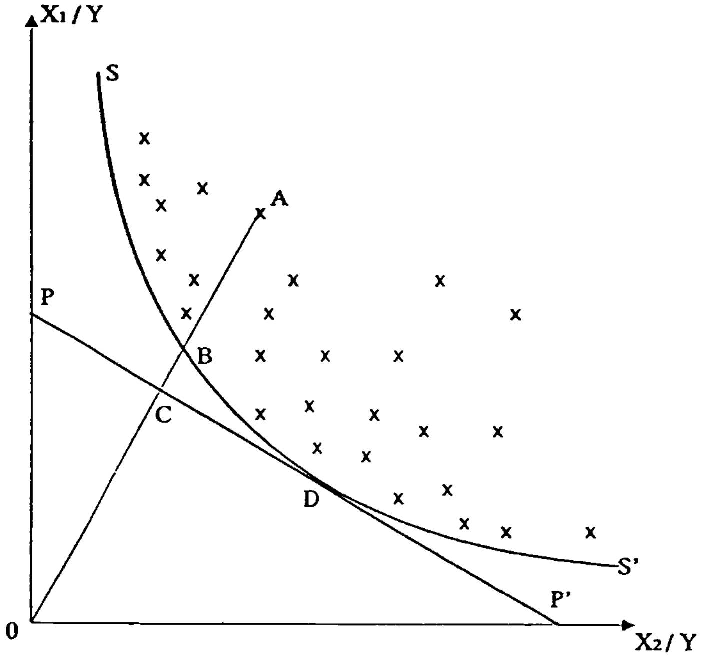

Fig 3.1-1 Frontier Function and Productive Efficiency

Price inefficiency is due to failures to adopt the least-cost technology defined by the current isocost line PP'. Farrell suspected of whether a high price efficiency is desirable (pp.261). Price efficiency measures the extent of a firm's adaption to a particular set of factor prices. In the short run it need not indicate any unavoidable errors in decision making, since, for example, ports which invested long ago may have had rather different expectations about future factor prices than would those which invested comparatively recently. Simliarly, in a period of expansion a port's best policy may be to operate for a time well above its optimal level of output, although this would imply a low price efficiency. Thus Farrell believed that price efficiency provides a good measure of efficiency in adapting prices only in a completly static situation.

Farrell's measure of technical efficiency measures the extent of deviations from the frontier production technology. Farrell maintained that it indicates "the undisputed gain that can be achieved by 'gingering up' the management" (pp.260). In other words Farrell's original intention is to measure managerial efficiency. Clearly to measure genuine efficiency requires all important factors of production except the managerial inputs to be included as explanatory variables in the production function. This also requires the quality of inputs except the quality of managerial inputs to be homogenous or the quality of inputs to be counted as further factors of production if they are heterogenous (as always). Recall that, in a classical regression model of production function, we shall build all important factors of production into the systematic part, leaving the mean of the disturbance term to be zero. In a frontier production function model, however, we shall deliberately leave managerial inputs outside the systematic part. It is the quantity or quality of managerial inputs that is the source of inefficiency we concern. However, it is easy said than done to measure input variables accurately and exhaustively. Failures to so will obscure policy implications of the efficiency estimates, since inter-firm efficiency may be partly attributed to the non-measurement of a further factor of production. The problem of the measurement of inputs will be discussed in Section 3.4. At this stage we need to elaborate on the exact meaning of managerial efficiency.

Even when we are free from measurement problems there is still room for doubt whether departures from the production frontier indicate "undisputed gains that can be achieved by gingering up the management". This should include X–inefficiency, which occurs due to motivational deficency at both management and worker level. The extent of X–inefficiency reveal gains that can be achieved through improving incentive structures of the management concerned. But departures from a production frontier need not be attributed to X–inefficiency only. They may simply represent the efficiency of a technology in relation to the best–practice technology. Clearly, with technical progress, technologies available recently are likely to be more productive than technologies available long ago. Once the technology is chosen, a firm is stuck with that particular technology until it is profitable to change it. At any moment an industry is likely to be living with different vintages of technology, which vary in productivity. In the short run, the inefficiency of a technology is not necessarily avoidable even in a X–efficienct firm, since it is unwise to replace the existing technology with the frontier technology at any cost.

Technical efficiency, managerial efficiency and X–efficiency are often used interchangably in economics literature. Leibenstein (1973) objected to technical efficiency being synonymous with X–efficiency:

> I use the term "X-efficiency" for what some writers may mean whey they speak of "technical efficiency" (for example, Farrell (1957)) or "efficiency in the engineering sense" (Schwartzman, 1973). My reason for this is to escape from some of the behavioural nuances and suggestions contained in the words "technical efficiency" (or, in some uses, "entrepreneurial efficiency"). One of the implications of "technical efficiency" is that there is some sort of a "central controller" of inputs who, at least in principle, is able to determine how the inputs are to be combined in order to pursue the objective of the firm (i.e. minimize costs). The only difficulty implicitly admitted is that this central controller is not quite as good at doing his job as he might be. His *technique* is off as it were. Hence, a firm may be technically inefficient. I believe that this involves an undesirable simplification of the nature of the firm, and hence I will use the more neutral concept of X-inefficiency to mean the extent to which a given set of inputs do not get to be combined in such a way so as to lead to maximum output.

There is some inconsistency in this quoted paragraph. At the begining Leibenstein seemed to emphasize that X-inefficiency is a better term than technical inefficiency for what he meant, but finally he seemed to infer that these two terms are different in substance. It is important to note that the difference between X-inefficiency and technical inefficiency is not just a matter of nuance.

In this monograph we formally distinguish between X-inefficiency and technical inefficiency and maintain that they represent two distinctive components of Farrell's "technical inefficiency", represented by the ratio of OB/OA in Fig 3.1-1. We replace the term "technical inefficiency" with the term non-price productive inefficiency. Technical inefficiency arises from the difference in the the frontier technology and the technology actually adopted due to putty-clay problem. By contrast X-inefficiency occurs because of failures to explore the maximum production possibility of the technology actually adopted. The distinction between these two efficiency notions are important because they have different policy implications. While X-inefficiency indicates the efficiency gains that can be achieved by gingering up the management, technical inefficency implies that the efficiency gains that can be achieved through technical progress. Technical efficiency may reflect conduciveness of a firm to technical progress and its managerial efficiency in investment decisions. But if we assume that knowledge of producers are imperfect so that they need time to adjust their production to the optimal level, technical inefficiency is unavoidable in the short run.

It is possible to decompose a deviation from the frontier into technical inefficiency and X-inefficiency. For instance, one may introduce variables in addition to factors of inputs in the frontier production function to describe the technical levels of firms in utlising the capital and labour inputs. Since the additional variables vary over firms using different technologies, firm-specific production functions can be derived from the common production function. While the X-efficiency measure can be constructed relative to the firm-specific production function, the technical efficiency measure can be obtained by comparing the firm–specific production function and the most efficient firm–specific production function.

The efficiency notions we have discussed so far are defined relative to a frontier technology that exhibits constant returns to scale and strong disposability. In non–parametric models more efficiency notions can be defined if we specify different characteristics for the frontier technology.

3.2 The Non-parametric Approach

Both non-parametric and parametric approaches were proposed by Farrell (1957). His non-parametric approach specifies the piecewise-linear, free disposable convex hull of the observed input-output ratio by some mathematical programming procedure. Farrell's non-parametric method has the advantage that no functional form is imposed on the data, but has the disadvantage of quite restrictive assumptions, namely, constant returns to scale and strong disposability of inputs. Secondly, Farrell illustrated his method for the case of a single output; the generalisation to permit multiple outputs by his approach is complicated. Finally, the efficiency estimated by Farrell's approach is susceptible to the presence of extreme observations and measurement error as the frontier is computed from a supporting subset of observations from the sample.

Following Farrell, many contributions have been made to construct a less restrictive piecewise-linear technology in order to generalise the non-parametric approach. Among the most important ones are the work by Charnes, Cooper, Rhodes (1978, 1979), and Banker (1984, 1), which is known as Data Envelope Analysis (DEA); and the work by Fare, Crosskopf, Lovell (1985) which we may call FCL models.

Both work via an axiomatic formulation from which is constructed a series of measures of efficiency relative to piecewise-linear technologies. But the efficiency measures derived from FCL models are more comprehensive than those derived from DEA models. Both radial and non-radial measures of *input-based efficiency*, *output-based efficiency* and *graph-based efficiency* are developed by FCL. By radial measurement overall productive efficiency can be decomposed into price and non-price productive efficiency. The latter can be further decomposed into *purely productive efficiency*, *congestive efficiency* and *scale efficiency*. The reference to sources of efficiency underscores one of the main contributions of the FCL approach.

In this study we will confine our attention to radial measures of input- and output-based productive efficiency for individual UK ports, as the virtues of the radial family of efficiency measures include the ease of computation, a straightforward cost and revenue interpretation, and the consequent decomposability (for details, see FCL (1985)). The remaining task of this section is to clarify the various notions of efficiency.

FCL models may be considered as an extension of Farrell's model in two respects. First, FCL formally distinguish a number of contexts in which a firm makes its input-output decisions. In this study we shall confine ourselves to two of them:

(i) a revenue maximisation context, in which a firm takes its inputs as being predetermined or exogenous;

(ii) a cost minimisation context, in which the firm takes its output as being predetermined or exogenous.

FCL maintain that different circumstances require different efficiency measures. Input efficiency, which is appropriate to the situation (ii), measures the efficiency of an input vector in the production of a predetermined output vector. Output efficiency, which is appropriate to situation (i), measures the efficiency of an output vector producible from a predetermined input vector.

Both input and output measures are radial in the sense that they search for the maximum proportional reduction in inputs or increase in ouputs. The distinction between input and output efficiency measures can be illustrated in Fig 3.2-1. For simplicity, consider a single-output Y and a single-input X reference technology denoted by FPF. Relative to FPF, the production plan in A is inefficient. The input measure of productive efficiency seeks a maximum reduction of input consistent with continued production of the same output, and it takes B as the efficiency reference point of A. The output measure of productive efficiency seeks a maximum output expansion consistent with continued usage of the same input and it takes C as the efficiency reference point of A.

The input measure is unequal to the output measure unless the technology is homogenous of degree one (FCL, 1985, pp.132). Since Farrell assumed constant returns to scale, there was no need in his framework to distinguish the two measures. But in general the efficient use of inputs does not necessarily imply the efficient production of output. Nor is the converse true.

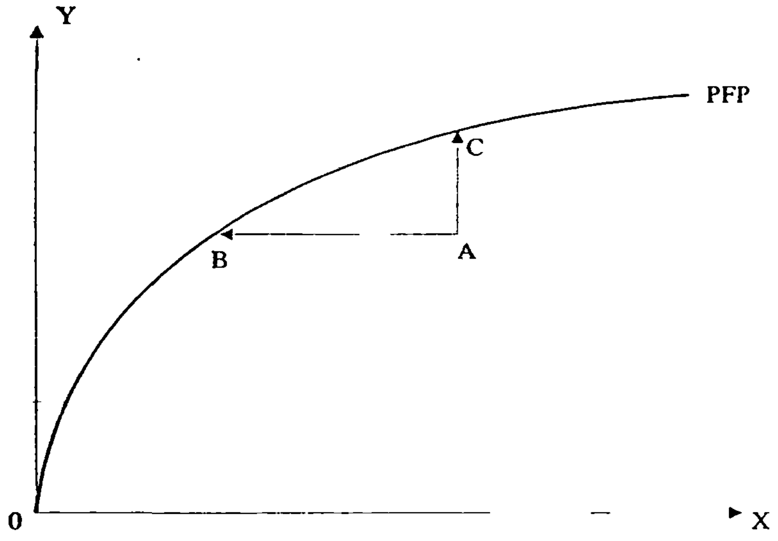

Fig 3.2-1 Input and Output Efficiency

Secondly, while the technology specified by Farrell is simple and restrictive, the technologies in FCL models are sophiscated and flexible. In Farrell's model the frontier technology is subject to constant returns to scale and strong disposability (we shall return to these shortly). By contrast, three reference technologies are distinguished in FCL models:

(i) the long-run competitive equilibrium technology, which exhibits constant returns to scale (CRTS) and strong disposability of inputs and outputs;

(ii) the strongly disposable technology, which exhibits variable elasticity of scale and strong disposability;

(iii) the weakly disposable technology, which exhibits variable elasticity of scale and weak disposability.

The variety of technologies enables us to define various notions of efficiency.

Consider Fig 3.2-2 which illustrates the three reference technologies by the the three isoquant lines, I_1, I_2 and I_3, for two inputs, X_1 (labour) and X_2 (capital), to produce a specified level of output Y (denoting either a single output or a vector of multiple outputs) in a cost-minimisation context where the input measure of efficiency is appropriate. The points along each technology represent different senses of the most efficient input combinations. The area above each technology is the corresponding input possibilities set.

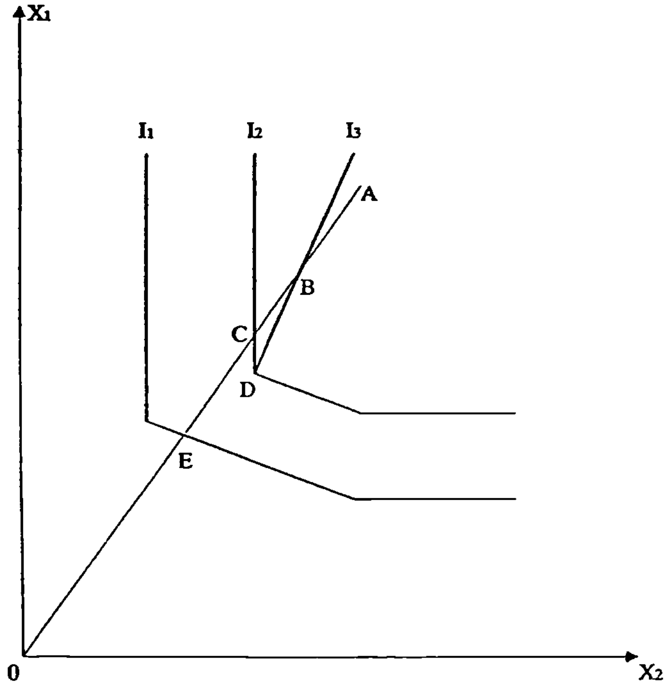

Fig 3.2-2 Input-Based Productive Efficiency

With constant returns to scale and strong disposability of inputs and outputs, the long-run competitive equilibrium technology denoted by $I_1(Y)$ provides the largest input possibility set required to produce Y. This is so because frontier firms operate at the most productive scale size. For a single-input and single-output case, the most productive size is simply the scale for which the average productivity measured by the ratio of total output to total input is maximised. In the case of multiple inputs, the most productive scale size is the scale that maximises the "average productivity" measured by the ratio of total outputs to total inputs for a particular input and output mix. The concept of the most productive scale size is closely related to returns to scale. Outputs per unit of inputs for a particular input and output mix would be maximised if and only if constant returns to scale prevailed. In order to maximise average productivity one would increase the scale size if increasing returns to scale prevailed, and decrease the scale size if decreasing returns to scale prevailed.

It is useful to distinguish between the problem of determining the most productive scale size for particular input and output mixes and the problem of determining the minimum cost mix of inputs and outputs on the basis of their relative prices (Banker, 1984, 2). Since prices are likely to be more volatile than the pure technological characteristics, Banker argued that estimation of merely the cost function is likely to retain its relevance for managerial and policy decisions for shorter period than the estimation of the purely technological relation between the physical quantities of inputs and outputs.

Another feature of the long-run competitive technology is strong disposability, as generally assumed in economics textbooks that technologies are monotonic. In other words, if one increases the amount of at least one of the inputs, it should be possible to produce at least as much output as one was producing originally. The technology is said to be strongly disposable or congestion-free, since if one can dispose costlessly of any inputs, having extra inputs around cannot do any harm (Varian, 1990, pp.303-304).

The strongly disposable reference technology denoted by $I_2(Y)$ is also assumed to exclude the possibility of congestion again but to exhibit increasing returns to scale or decreasing returns to scale. Since firms that adopt this technology fail to maximise average productivity, $I_2(Y)$ lies above the long-run competitive equilibrium technology and the input possibilities set shrinks accordingly.

The monotonicity or strong disposability of the technology implies positive marginal productivity. However, in accordance with the law of diminishing returns, if more and more of a variable factor is applied to a fixed quantity of other inputs, eventually the resulting increases in output must diminish. Whenever this happens and the variable input is not freely disposable for one reason or another, the technology is said to be congestive in the variable factor. Technologies exhibiting congestion are frequently found in agriculture, transport, and engineering industries where a proper subset of production factors is kept fixed and increases in the others may obstruct output (Fare, 1980). This may be justified in two ways (Heathfield and Wibe, 1987, pp.26–27). The first relies on the heterogeneous nature of the fixed inputs. At the initial stage of production only the most productive parts of the fixed inputs are in use. But as output expands more of the least productive parts of the fixed inputs are pressed into service and so the marginal product of the variable input declines. This could be the case in the port sector where the fixed inputs are land and water area. At first only the most suitable sites, which are close to urban centres or require less dredging, are chosen to build terminals. But as output expands the quality of the capital inputs is poorer and poorer and hence the marginal product of labour declines. The second relates to the optimum factor ratio given by quantity of the fixed input. Before the optimal ratio is reached the variable input will become more productive as it increases. Beyond the optimum, the factor ratio is less and less optimal as the variable input increases and eventually the marginal product of the variable input will become negative. An example of this in the port sector of this country could be the now abolished labour scheme which prohibited casual employment of dock workers. Under the scheme, port employers were not permitted to dismiss registered dock workers without consulting with joint boards of employer and trade union representatives. With dramatically declining labour requirements as a result of technical progress in the industry, the labour/capital ratio is less and less optimal with a redundant labour force. Our attention will be confined to the second type of congestion in technology which is due to the non-optimal factor ratio. Returning to Fig.3.2-2, if one of the inputs, say labour X_1, is not strongly disposable, congestion in X_1 will cause the technology denoted by $I_3(Y)$ to be backward-bending so that the input possibilities set shrinks further. The backward-bending frontier indicates that the technology is not monotonic: the marginal product of labour is negative.

Against these reference technologies various notions of productive efficiency can then be measured. Following FCL it is useful to categorise three primary measures and two derived measures of non-price productive efficiency.

The three primary measures include non-price productive efficiency OTE, weakly productive efficiency WTE and purely productive efficiency PTE. Again consider Fig.3.2-2 which illustrates the various input-based notions of efficiency diagrammatically. The observed input combination is denoted by A. First of all, relative to the long-run competitive equilibrium technology $I_1(Y)$, the overall point of efficient production with the same factor ratio as A would be E. The input-based measure of non-price productive efficiency (IOTE) for A relative to $I_1(Y)$ would be

$$(3.2\text{-}1) \qquad IOTE = OE/OA$$

The point C on the strongly disposable $I_2(Y)$ represents a weak point of efficient production, since the point C is not attainable with the congested technology $I_3(Y)$. But the point D is attainable with $I_3(Y)$ as well as with I_2. By disposing CD units of X_1, the point C is attainable. The input-based measure of weakly productive efficiency (IWTE) for A defined relative to $I_2(Y)$ would be

$$(3.2\text{-}2) \qquad IWTE = OC/OA$$

Finally, against the weakly disposable and non-CRTS technology $I_3(Y)$ the input-based measure of purely productive efficiency (IPTE) which is due to production in the interior of $I_3(Y)$ would be

(3.2-3) $\quad \text{IPTE} = OB/OA$

Two points should be noted about these three primary measures. First, in Farrell's framework IOTE, and IWTE and IPTE are equal. This is so because Farrell assumed constant returns to scale and strong disposability, and hence the three reference technologies distinguished in the FCL framework coincide. But unless we are convinced that the frontier technology can only be characterised with constant returns to scale and strong disposability it is necessary to distinguish the three measures from one another. Second, for the reason explained in section 3.1 IPTE is hypothesized as both technical efficiency and X-efficiency.

Divergency in the values of the three primary measures implies the existence of two additional categories of inefficiency, known as congestive inefficiency and scale inefficiency. Given the three primary measures, the latter two measures can be derived. Congestive inefficiency occurs because of production on the backward-bending segment of the technology where inputs are not strongly disposable. To measure input congestion radially, one needs to determine by how much an input vector can be radially reduced to reach the closest input-congestion-free technology (i.e. I_2) from the congested technology (I_3). Such an input congestion measure can be defined as the ratio of IPTE and IWTE, i.e.

(3.2-4) $\quad \text{ICE} = \text{IWTE}/\text{IPTE} = OC/OB$

Scale efficiency occurs because the firm is not operating at the most productive scale consistent with the long-run competitive equilibrium. Naturally such an input measure of scale efficiency relates to the divergency bewteen I_1 and I_2

and should then be derived from IWTE and IOTE, i.e.

$$(3.2\text{-}5) \qquad ISE = IOTE/IWTE = OE/OC$$

Unlike purely productive inefficiency and congestive inefficiency, scale inefficiency as a result of departure from the long-run competitive equilibrium is not necessarily an error on the part of the firm concerned. It is inefficient from the social point of view.

It is easy to see that non-price productive efficiency (IOTE) can be decomposed into the categories of purely productive efficiency, congestion efficiency and scale efficiency, namely

$$\begin{aligned}(3.2\text{-}6) \qquad IOTE &= (IPTE)(ICE)(ISE)\\ &= (OB/OA)(OC/OB)(OE/OC)\\ &= OE/OA\end{aligned}$$

In a similar vein, radial measures of output-based non-price productive efficiency can be constructed (FCL, 1985, pp.79–102).

In short, purely productive efficiency denoted by PTE (in the form of either X-efficiency or technical efficiency or both), congestive efficiency denoted by CE and scale efficiency denoted by SE are three mutually exclusive and exhaustive components of non-price productive efficiency denoted by OTE. OTE can occur in any one way, any two ways and all three ways but in no other ways. The FCL framework thus enables us to define productive efficiency in a systematic manner as compared with Farrell's framework.

3.3 The Non–parametric Frontier Models

In this section FCL's non–parametric models are modified for British ports in order to bring the notions of purely productive efficiency, congestion efficiency and scale efficiency into the same framework.

It should be clear by now that different notions of efficiency are defined against different reference technologies. In non–parametric models the reference technologies are subsets of the input and output correspondences. A production technology transforming factors of production $X=(X_1,X_2,\ldots,Xn) \in R(n)+$ into net outputs $Y=(Y_1,Y_2,\ldots,Ym) \in R(m)+$ can be modelled by an input correspondence $Y \to I(Y) \subseteq R(n)+$, or inversely by an output correspondence $X \to P(X) \subseteq R(m)+$. I(Y) gives all possible input vectors which yield at least Y. Inversely P(X) gives all possible output vectors obtainable from X. FCL assumes that the input correspondence satisfies the following axioms:

L.1 0 does not belong to $I(Y)$ for $Y \geq 0$, and $I(0) = R(n)+$;

L.2 If $\|Y(l)\| \to +\infty$ as $l \to +\infty$, then $\overset{\infty}{\cap} I(Y(l))$ is empty;

L.3 If $X \in I(Y)$, $\lambda X \in I(Y)$ for $\lambda \geq 1$;

L.4 I is a closed correspondence;

L.5 $I(\theta Y) \subseteq I(Y)$ for $\theta \geq 1$.

L.1 means that a semi–positive output cannot be obtained from a null input vector and that any non–negative input vector yields at least zero output. L.2 means that a finite input cannot produce infinite output. L.4 is a mathematical requirement imposed to enable input isoquants to be defined as subsets of the boundary of the input sets I(Y). L.3 means that a proportional increase in inputs does not decrease outputs. L.5 means that a proportional increase in output cannot be obtained if inputs are reduced. L.3 and L.4 are referred to as weak disposability of inputs and outputs respectively. These are equivalent to assuming that marginal products are not restricted to be non–negative.

Occasionally stronger axioms than L.3 and L.5 are needed:

L.3.S $t \geq X \in I(Y) \rightarrow t \in I(Y)$;

L.5.S $s \geq Y \in I(s) \subseteq I(Y)$.

L.3.S states that an increase in inputs, including but not limited to a proportional increase in inputs, does not lead to a decrease in outputs. L.5.S states that an increase in outputs, including but not limited to a proportional increase, cannot be obtained if inputs are reduced. In other words marginal products are restricted to be non–negative. L.3.S and L.5.S are referred to as strong disposability of inputs and outputs.

Given the data available we are able to identify two inputs (labour X_1 and capital X_2) in the production of a single output Y in a given period of time, where for k British ports in the sample X_1, X_2 and Y are all k–element column vectors. Assume that the broad port production technology is piece–wise linear and modelled by an input correspondence I(Y) or output correspondence P(X) which satisfies the properties (L.1–L.5) or (P.1–P.5) inversely related to (L.1–L.5) (see FCL, 1985, pp.25). Further we use M to denote a (k,1) vector of observed output and N to denote a (k,2) matrix of observed inputs for k ports, and $Z=\{Z_1,Z_2,\ldots,Z_k\}$ to denote the activity (intensity) level of each of the k activities.

The reference technology of British ports $I_3(Y)$ with no restriction of CRTS and of strong disposability is the subset of input set I(Y) which satisfies no more than L.1–L.5, i.e.

$$(3.3\text{-}1) \qquad I_3(Y)=(X:U.Z.M=Y,\ Z.N=V.X;\ U,V\in(0,1],\ Z\in R(k)+)$$

where $\Sigma Z_i=1$ to allow for increasing, constant and decreasing returns to scale; the parameters U and V allow for radial scaling of the original observations and their convex combinations.

The reference technology $I_2(Y)$ with restriction of strong disposability but not of CRTS is the subset of I(Y) which satisfies L.1, L.2, L.3.S, L.4 and L.5.S., i.e.

(3.3-2) $$I_2(Y)=\{X: Z*M \geq Y,\ Z*N \leq X,\ Z \in R(k)+\}$$

where again $\Sigma Z_i=1$ to allow for increasing, constant and decreasing returns to scale; The inequalities replace strict equalities on (3.3-1) to allow for strong disposability.

The reference technology $I_1(Y)$ with restrictions of both strong disposability and CRTS is the same as $I_2(Y)$ except that the sum of Z_i is not restricted to unity.

Given these constructions a series of linear programming models can be formulated accordingly in order to calculate the various efficiency measures.

Recall that non-price productive efficiency OTE is decomposed into purely productive efficiency PTE, congestive efficiency CE and scale efficiency SE, where CE is derived from PTE and weakly productive efficiency WTE according to Eq(3.2-4), and SE is derived from OTE and WTE according to Eq(3.2-5). Therefore we only need to consider models for three primary input measures of OTE, PTE and WTE.

The input measure of non-price productive efficiency IOTE for an observation (X_0,Y_0) relative to the technology $I_1(Y)$ can be calculated from the following linear programming problem.:

(3.3-3)
$$\begin{aligned} &\text{Min} && IOTE \\ &\text{Subject to} && Z'*M \geq Y_0 \\ & && Z'*N \leq X_0*IOTE \\ & && Z \geq 0 \\ & && IOTE \geq 0 \end{aligned}$$

The input measure of weakly productive efficiency IWTE for the observation (X_0,Y_0) relative to the technology $I_2(Y)$ can be calculated from the following linear programming problem:

$$(3.3\text{-}4) \qquad \text{Min} \quad IWTE$$
$$\text{Subject to } Z*M \geqslant Y_0$$
$$Z'*N \leqslant X_0*IWTE$$
$$\sum_{i=1}^{k} Z_i = 1$$
$$Z \geqslant 0$$
$$IWTE \geqslant 0$$

According to FCL (1985, pp.183) we also have to compute weakly productive efficiency on the star-input correspondence IWTE* to identify sources of scale inefficiency. If there is scale inefficiency at (Y,X), then it is caused by increasing returns to scale if and only if IWTE*<IWTE, and it is caused by decreasing returns to scale if and only if IWTE*=IWTE. The linear programme for IWTE* is the same as that for IWTE in (3.3-4) except the restriction of returns to scale in the former should be $\Sigma Z_i \leqslant 1$ rather than $\Sigma Z_i = 1$.

The input measure of purely productive efficiency IPTE for the observation (X_0,Y_0) relative to this technology can be calculated from the following non-linear programming problem:

$$(3.3\text{-}5) \qquad \text{Min} \quad IPTE$$
$$\text{Subject to } U*Z'*M = Y_0$$
$$Z'*N = IPTE*V*X_0$$
$$\sum_{i=1}^{k} Z_i = 1$$
$$0 < U \leqslant 1$$

$$0 < V \leqslant 1$$

$$Z > 0$$

$$IPTE \geqslant 0$$

which is a non-linear programming problem and can be transformed into the following linear programming problem:

$$(3.3\text{-}6) \qquad \text{Min} \quad IPTE$$

$$\text{Subject to } Q*M = Y_0*S$$

$$Q*N = X_0*IPTE$$

$$\sum_{i=1}^{k} Q_i \geqslant 1$$

$$S \geqslant 1$$

$$Q \geqslant 0$$

where $S = 1/U*V$, $Q = Z/V$. Minimisation of IPTE requires that the restriction $\Sigma Q_i \geqslant 1$ reduce to $\Sigma Q_i = 1$. The equality must hold since otherwise a proportionate reduction in each element of Q would allow a lower value of IPTE, which is the minimand.

From their respective definitions in Fig 3.2-2 it is clear that IOTE $\leq$ IWTE $\leq$ IPTE. This can also be verified mathematically. The difference between Eq(3.3-3) and Eq(3.3-4) is the extra constraint that the Z_i sum to unity in the latter. It is then obvious why IOTE should be less than IWTE. To explain the relationship between IWTE and IPTE, we can rewrite Eq(3.3-5) as

$$(3.3\text{-}7) \qquad \text{Min} \quad IPTE$$

$$\text{Subject to } Z'*M = Y_0*U$$

$$IPTE*X_0 = (Z'*N)/V$$

$$\sum_{i=1}^{k} Z_i = 1$$

$$0 < U \leq 1$$

$$0 < V \leq 1$$

$$Z > 0$$

$$IPTE \geq 0$$

Both free variables U and V are bounded within (0,1]. Clearly when U=V=1, Eq(3.3–7) is equivalent to Eq(3.3–4) and hence IWTE=IPTE. In this case the strongly disposable technology coincides with the weakly disposable technology. When U or V is less than unity, Y_0*U or (Z'*N)/V in Eq(3.3–7) must be larger than Y_0 or Z'*N in Eq(3.3–4). This means that the minimisation of IPTE has tighter constraints than the minimisation of IWTE, and hence that IWTE < IPTE.

For the output correspondence, P(X) axioms P.1–P.5 and P.3.S and P.5.S inversely related to the above axioms can be imposed (see FCL, 1985, pp.25), and the corresponding output–based reference technologies can be constructed. In a similar vein, one can construct linear programming models to calculate output efficiency, and these are given in Appendix 3.3–1.

3.4 Variables and Data

The source of data for this thesis was the annual reports and financial accounts published by port authorities in Britain during 1983–1990. Although there are 100 commercially significant ports in Britain, not all of them provide information on all variables and some do not publish annual accounts at all. Having deducted non–commercial ports (e.g. fishing ports or harbours mainly involved in navigation and conservancy or off–shore supply) from those which do provide annual accounts, at best one can have 37 observations a year. However, the samples do cover almost all the well-known British ports and all the important ports in each category of ownership. The samples also have a fair coverage of ports of different size, including *major ports*, *medium ports* and *small ports* (a classification adopted by the British Ports Federation). Associated British Ports are taken as one unit since the group does not provide data at disaggregated level.

A production frontier is not observable. It can only be estimated from a data set of relevant input–output variables. An accurate representation of the frontier technology depends not only on how well the frontier is modelled, but also on how well the variables are measured. Before constructing the variables, however, one must know the production process that the technology refers to. For instance, steel production consists of three processes: mining, iron production and steel production. Different processes require different inputs to produce different outputs. The mining process 'produces' iron ore by applying capital and labour to the land. The production of iron requires capital and labour and iron ore. The steel producing process uses capital and labour and iron. Alternatively, the three stages can be regarded as a single process. In this case the inputs would be capital, labour and iron ore and output would be steel. Needless to say, the capital and labour inputs used in different processes are different.

The process of port production is complex, consisting of pilotage, towage, berthing, cargo loading and unloading, and warehousing. Also modern ports tend to diversify beyond traditional port activities into distribution, related transportation and property sale, etc. Ideally, it would be best to concentrate on one particular production process, for example, cargo handling. But this is impossible with the data available. The port production process considered in this study is the activity of the port as a whole. This leaves room for doubt on the interpretation of efficiency measures since the activities of a given port may not be the same as those represented by the corresponding point on the frontier. Nevertheless, in contrast to continental European ports, the internal structure of British ports is relatively uniform. Although there are exceptions, the duties of British port authorities are relatively comprehensive. Britain's port activities are thus not hopelessly uncomparable. In addition, what concerns us is the relative efficiency of different forms of port ownership rather than of individual ports. It is hoped that, by averaging efficiency for each group, the effect of the diversity of port activities will be reduced. In the final chapter we shall consider to what extent the diversity in activity can account for inter-port efficiency.

The measurement of inputs fraught with difficulties. For instance, it is well-known that capital represents a particularly difficult problem, which has provoked, and continues to provoke, a great deal of controversy. In the context of frontier estimation, the most worrying problem is, however, not how to define input variables, but how to treat the heterogeneity of factors of production (Farrell, 1957, pp.260). The productiveness of different sets of equipment may vary considerably. So would the natural fertility of farmers' land, or the quality of the labour force. Quality differences in a factor favour a firm using relatively high grade. Whenever this is so, there is room for doubt whether efficiency measures constructed relative to a frontier are genuine measures of managerial efficiency. This problem is the same in effect as the problem of omission of one of the factors, which would give a firm that used relatively much of this omitted factor a relatively high efficiency. One may consider inability to measure quality difference in a factor as an omitted factor: quality of the factor.

Nevertheless, the correct measurement of all relevant factors is subject to information available, and, in practice, information is notoriously limited. For this reason, Farrell believed that the productive efficiency of a firm must always, to some extent, reflect the quality of its inputs, which is not measured in frontier models. From practical point of view, while one should take every effort, given information available, to reduce the extent of measured efficiency attributed to quality differences and unobserved factors through better definition of variables and specification of the frontier model, interpretation to account for interior points should be cautious when preliminary work on data processing is constrained by information available. One could also, use partial or total correlation analysis, to investigate the factors which influence estimated efficiencies.

With the data available in the financial reports, we are able to identify one output and two inputs (labour and capital) for British ports.

Output Y is defined as turnover in thousand pounds, which consists of the amount receivable in respect of port services provided to third parties. In some ports this also includes revenue from property sales and rent. As a matter of fact the value of turnover serves as an aggregate measure of the multiple services provided by a port.

There are several serious problems associated with this measure. The first is the use of a gross rather than a net output measure. We note that the numerator of all productivity ratios should be net output or at least a proxy variable for net output. It is the results that are achieved by the factors employed within the firm concerned which is necessary to relate to the quantity of such factors. Non-factor inputs such as bought-in materials, fuels, component parts and services are the product of other factors from outside the industry concerned. The net output of the port industry is ideally defined as the difference between the value of its gross output and the value of its non-factor inputs. It is possible in principle to calculate figures of value added for many ports based on the financial data provided in their company reports. However, the items reported in the financial accounts are not standardized for all ports, and this means that some observations would be missing if value added is used as a definition of output [1]. Since the proportion of non-factor input costs in the value of gross output is not as significant as in other industries, because the port industry is a service industry, it is hoped that the gross output measure we have adopted is not a poor proxy of the net output measure which should ideally be used.

Since we in fact use port prices as weights to aggregate the multiple services provided by ports, another problem is that turnover would not serve as an appropriate aggregate measure of the multiple services if port prices fail to reflect the real costs of port facilities and services. The composition of port facilities and services varies across ports, and this could lead to a distortion in valuing the true level of port activities. Port prices consist of two parts: port dues on vessels and cargoes for the use of port facilities, and port charges for the use of port services (e.g. cargo-handling charges). The fixing of port charges is subject to negotiation between port operators and ship operators in specialised terminals. In common-user terminals port charges also reflect the demand and supply situation. Since the markets for port services in the UK are quite competitive, it is reasonable to assume that port charges are more or less in line with port costs. Port dues, on the other hand, are fixed by port authorities. Although they may be reviewed every year or so in line with general price index or other considerations, they bear little relationship with real costs of port facilities. If we agree on the short-run marginal cost pricing principle, the opportunity cost of some port facilities (e.g. capital dredging) is zero when the channel is under-utilised, and should reflect the scarcity of the facilities when a port concerned is congested. These economic

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[1] At the initial stage of research it was worrying that the size of actual samples of British ports was too small to fit production frontiers. It was later realised the smallness of sample size can be overcome by pooling cross-sectional data. Further research is planned in which the efficiency measures will be recalculated on the basis of estimated value added.

principles are rarely considered in the fixing of port dues. Nevertheless, the amount receivable from collecting port dues is not a major ingredient of port incomes as compared with the amount received from port charges in a typically commercial port. The effect of "incorrect" prices might therefore be negligible.

Labour input X_1 is defined as total staff costs consisting of wages, salaries and social security costs in thousand pounds. In ports of the National Dock Labour Scheme this also includes the National Dock Labour Board Adminstration levy and the National Volunteer Severance levy. We deliberately include these in order to reflect the impact of the labour scheme on efficiency.

Capital input X_2 is measured by the net-book value of fixed tangible assets in thousand pounds, and usually includes land, buildings, dredging, dock structures, roads, plant and equipment etc. The gross value of freehold land required for port operations is based on the market price. The gross value of other fixed assets is based on cost where this is known, or on engineering estimates of what the cost would have been at the date of purchase and construction. Depreciation in British ports is provided, on assets other than land, on a straight-line basis over their estimated lives.

A better measure of capital input is replacement cost. Historical cost fails to reflect the opportunity cost or real cost of capital assets. In the port industry where fixed assets are typically durable, the adoption of historical cost is likely to create bias against relatively newly-built ports (e.g. Felixstowe). For some ports which have not undertaken major investments for years (e.g. Liverpool) the net book value based on a straight-line basis tend to undervalue the real costs of their capital assets. This does not apply to the value of land which is based on the market price. When information is not available on replacement cost, a better approach would be to adopt a physical measure. For instance, one can design a proxy measure of capital input which is a function of the size of quays, water area, and capacity of cranes. However, since different parties (i.e. port operators other than the port authority) may be involved in a single port, a port-by-port investigation would be necessary to identify the fixed capital assets which belong to each port authority.

The two inputs available to us may not be sufficient to tie down a frontier production function. An important factor which is likely to account for inter-port efficiency is the port location. Every port must possess water area and land to fulfill its functions, but the quality of port sites varies across ports. Some ports may claim inherent cost advantages over others because of tidal characteristics and estuary depth. The measurement of the locational factor is difficult, although not impossible. This is so because the factor is multi-dimensional. For example, a port located at the estuary mouth requires less capital and maintenance dredging but this advantage may be offset by the need to construct breakwaters and stronger quay walls, which would not be necessary if the port were built at the estuary head.

The omission of some relevant factor input in the deterministic model produces biased efficiency estimates in favour of firms using relatively much of that factor. In stochastic models this will result in the inconsistency of efficiency estimates. One of the difficulties which stochastic frontier models suffer from is the requirement of non-independence of regressors and the inefficiency term (Schmidt and Sickles, 1984). But when some relevant factor (say locational factor) is omitted, it may be incorrect to maintain this assumption. A port with a favourable location gives a higher productivity. This may well imply relatively higher labour and capital inputs because of the marginal productivity conditions. In consequence the inefficiencies (one-sided error component) will not be independent of the regressors. In chapter 4 we shall tackle the locational effect in a panel data model. It is possible to argue, at this stage, that the problem may be less serious than first appears. Some of the locational effect may already be reflected in the aggregate capital variable which includes land. Since the value of land is based on market price, this may reflect locational advantage of port sites to some extent.

Production in ports, as production in other transport sectors, is special in the sense that port customers also contribute by providing factors of production: i.e.

ship and cargo time (Goss, 1990, 1). The first involves the opportunity cost of ship time, roughly equivalent to the time-related vessel operating costs at port (wages, insurance, repairs and the hotel load level of fuel consumption) plus profit foregone elsewhere. The second mainly relates to the value of time taken to keep cargo at port (for example the cost of borrowing money to finance goods, although it is by no means confined to this). From the social point of view these are also an important component of port costs. Efficiency measures would be more meaningful if ship and cargo time could be counted as an input variable along with capital and labour. Unfortunately this was also impossible with the data available.

We are fully aware of the fact that the data set is far from ideal. With the information available there is little preliminary work that can be done on the measurement of inputs and output. An alternative data source is *Port Statistics* published by the British Ports Federation, in which detailed output data in terms of tonnage are available. We have also collected data on the number of port employees by occupation. Unfortunately, there are no capital data consistent with these output and labour data.

For the purpose of this study, the measurement problems, however, may be less serious than it appears. Since what concerns us is the relative efficiency of port ownership rather than of individual ports, mere bias in the measurement of input and output variables will not matter, so long as it is spread evenly over different ownership groups. It is when there are systematic differences between ownership groups in the input and output variables, that an ownership group's efficiency will reflect the bias as well as its managerial efficiency. To compare relative efficiency of different forms of port ownership, we will compare their average efficiency. Although we do not expect the bias in the measurement to disappear over different ownership groups, it is not difficult to believe that the effect of the unobserved factor can be reduced by averaging the efficiency measures of each ownership group.

3.5 Non-parametric Estimates of Productive Efficiency

In order to estimate deterministic measures of efficiency by the non-parametric approach, 7 linear programming problems (3 primary input measures, 3 primary output measures and one measure of weakly productive efficiency on the star correspondence) have to be calculated for each port in each year. The linear programming models have been applied to the cross-section data sets of UK ports for the period 1985-1990. The annual samples of the 6 years consist of 192 observations in total. Thus in total 1344 linear programming problems have been calculated, using the mathematical programming package *GAMS*[1]. The estimates of both input and output measures of productive efficiency, both overall and by components, for sample ports in each year of 1985-1990 are given in Appendix 3.5 to this chapter.

Recall that, by both input and output measures, non-price productive efficiency OTE can be decomposed into purely productive efficiency PTE, congestive efficiency CE and scale efficiency SE. Also recall that we denote IOTE, IPTE, ICE and ISE for corresponding input measures of and OPTE, OCE and OSE for corresponding output measures of overall non-price productive efficiency (OTE), purely productive efficiency (PTE), congestive efficiency (CE) and scale efficiency (SE) respectively. The most efficient score for both input and output measures is unity. The value for input measures ranges from zero to unity, indicating the cost saving that results from moving from the observed point to the point with same factor proportion on the frontier: input cost at the reference point is the fraction (indicated by the efficiency value) of input cost at the observed

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Note: [1] *GAMS* (the acronym stands for General Algebraic Modelling System) which is designed to make the construction and solution of large and complex mathematical programming is developed in the Development Research Centre of the World Bank. See Anthony Brooke, David Kendrick, and Alexander Neeraus, 1988, Gams: A User Guide, The Scientific Press.

point for any given input prices. The value for output measures is not less than unity, indicating the revenue increase that results from expanding production from the observed point to the reference point: the output revenue at the reference point is the multiple (indicated by the efficiency value) of the observed output revenue for any given output prices. Thus a port is more efficient if its input measure is higher or its output measure is lower.

The estimates of IOTE and OOTE for 27 sample ports in 1990 are plotted in Fig 3.5-1. The picture that emerges from Fig 3.5-2 is one of substantial variation in overall non-productive efficiency across British ports. The value of IOTE ranges from 1.0 for Mersey (i.e. Liverpool) to 0.2 for Manchester. This is equivalent to the value of OPTE ranging from 1.0 for the most efficient observation to 5.0 for the least efficient observation. In theory, given its factor ratio, the most inefficient port could increase revenue by 4 times or decrease costs by 80 per cent, if it managed to move towards the long-run competitive equilibrium technology.

It seems difficult to believe the potential of improvements that has been revealed. There are two explanations for this. Firstly, the reference technology arising from the long-run competitive equilibrium is the most rigorous yardstick we use to measure port performance. Departures from the most rigorous frontier include technical inefficiency, X-inefficiency, congestive inefficiency and scale inefficiency, whether they are inefficiencies in a private or social sense.

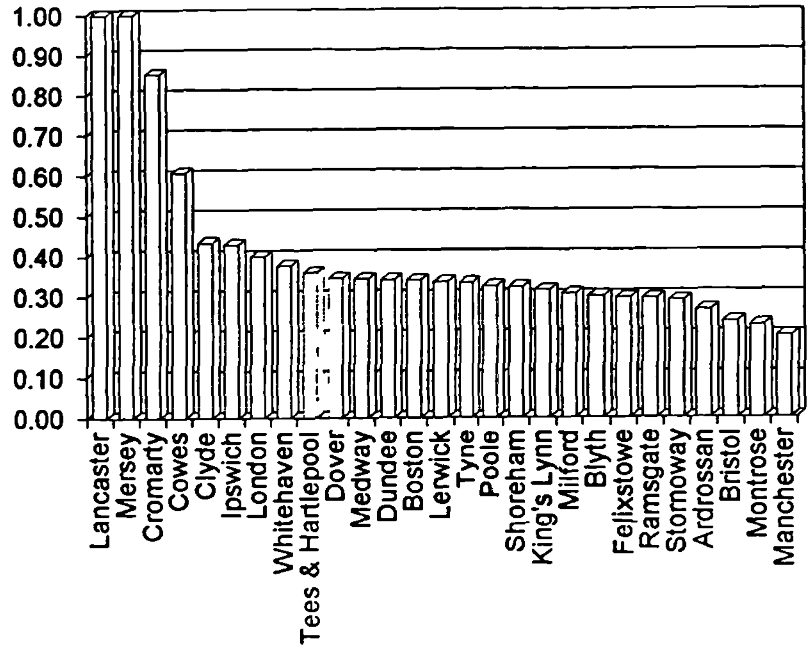
Secondly, departures from the deterministic frontier also include exogenous influences (random shocks or non-random factors) beyond the control of producers. Non-parametric efficiency estimation applied to industries where exogenous influences are more significant tend to show larger variation in estimates. For instance, in the work done by Farrell (1957), which applied the method to American agriculture, the range of efficiency values was as large as ours. One of the most important sources of random shock in the port industry is the fluctuation in demand for port services, which is derived from demand for raw materials, intermediate and final products. Demand fluctuations in all markets will be mirrored in the port market. If demand affects ports evenly, it may have little effect on relative performance which is measured against the best-practice technology. Since ports differ in cargo mix, demand is likely to affect ports differently. The influence of random shocks on productive performance can be largely wiped out by using the stochastic frontier technique which we will adopt in the next chapter. There are also non-random influences beyond the control of ports. Location is such a factor. For instance, the gap between Liverpool and Manchester may be largely attributed to the relative location advantage of the former over the latter. Nevertheless we still believe the existence of inter-port efficiency, though the potential for improvements may be overstated. For example, as far as Liverpool is concerned, successful marketing of this port in recent years is also an important contributing factor to its performance.

Fig 3.5-2, Fig 3.5-3 and Fig 3.5-4 depict possible sources of overall non-price productive inefficiency, namely PTE, CE and SE by both input and output measures. The direction of improvements in overall non-productive efficiency can be indicated by these components.

An important component of non-price productive inefficiency appears to be PTE by both input and output measures. In 1990 London, Felixstowe, Liverpool, Ipswich, Montrose and Lancaster were efficient in terms of PTE. Since purely productive inefficiency could be either X-inefficiency or technical inefficiency, there was considerable scope for other ports to raise their PTE value either by improving internal organisation or through technical progress.

SE was another important component responsible for considerable non-price productive inefficiency in the industry. This component arises because of failures to choose the most productive scale size. Whether actual scale size should be increased or decreased depends on the nature of returns to scale.

(a) Input Measure of Overall Productive Efficiency



(b) Output Measure of Overall Productive Efficiency

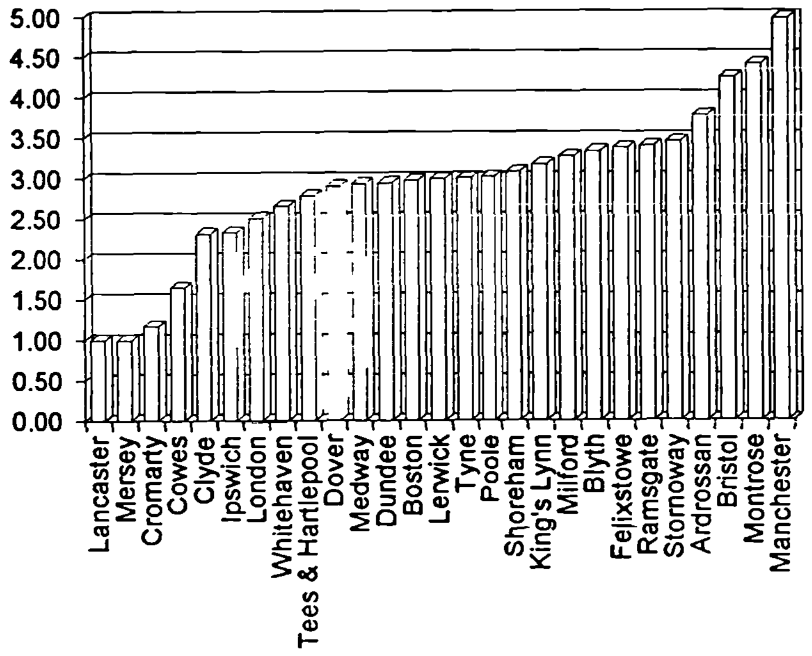
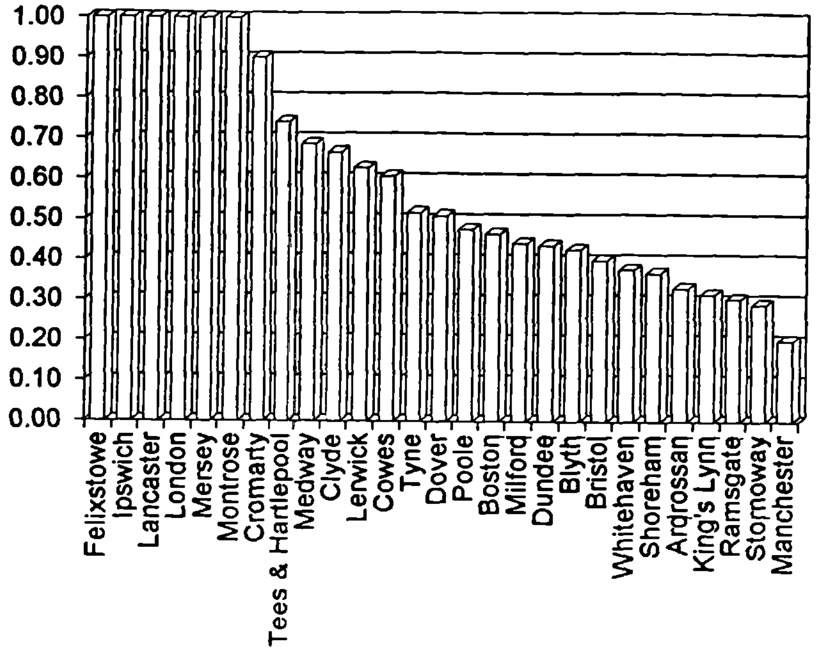


Fig 3.5–1 Non–Price Productive Efficiency of British Ports in 1990
(Non–parametric Measure)

Note: The value of input measure is the fraction of the observed cost in relation to the minimum cost on the frontier for any given input prices; The value of output measure is the multiple of the maximum revenue on the frontier in relation to the observed revenue for any given output prices. For both measures the most efficient score is 1.0.

(a) Input Measure of Purely Productive Efficiency



(b) Output Measure of Purely Productive Efficiency

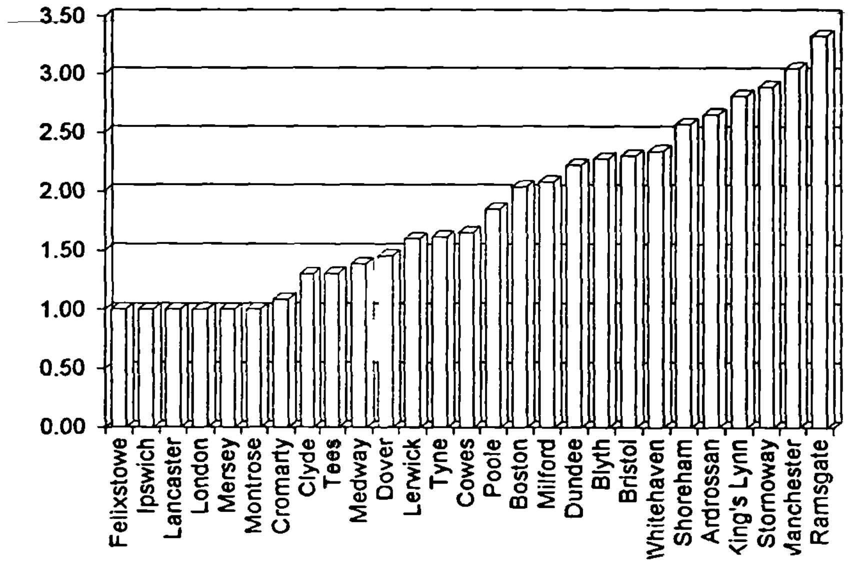
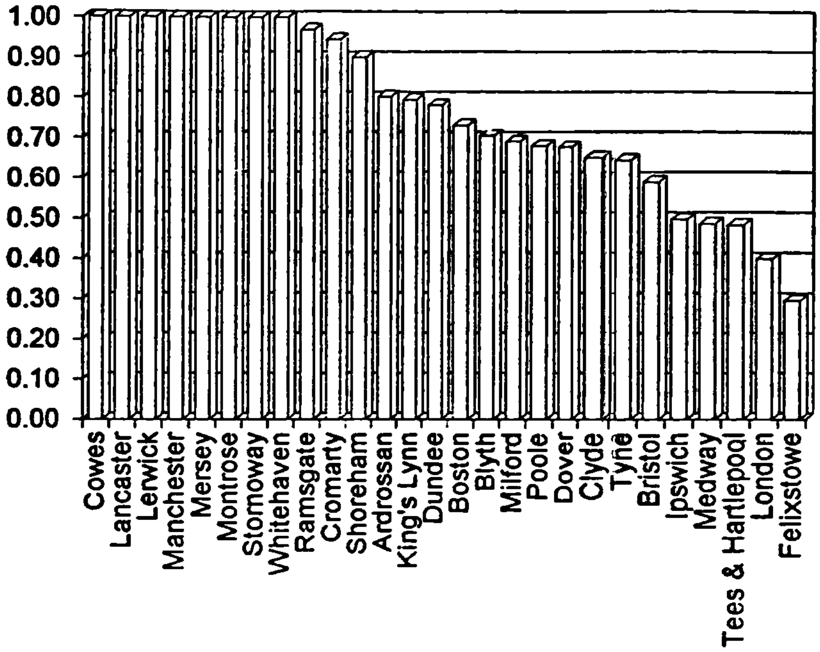


Fig 3.5-2 Purely Productive Efficiency of British Ports 1990
(Non-Parametric Measure)

Note: The value of input measure is the fraction of the observed cost in relation to the minimum cost on the frontier for any given input prices; The value of output measure is the multiple of the maximum revenue on the frontier in relation to the observed revenue for any given output prices. For both measures the most efficient score is 1.0.

(a) Input Measure of Scale Efficiency



(b) Output Measure of Scale Efficiency

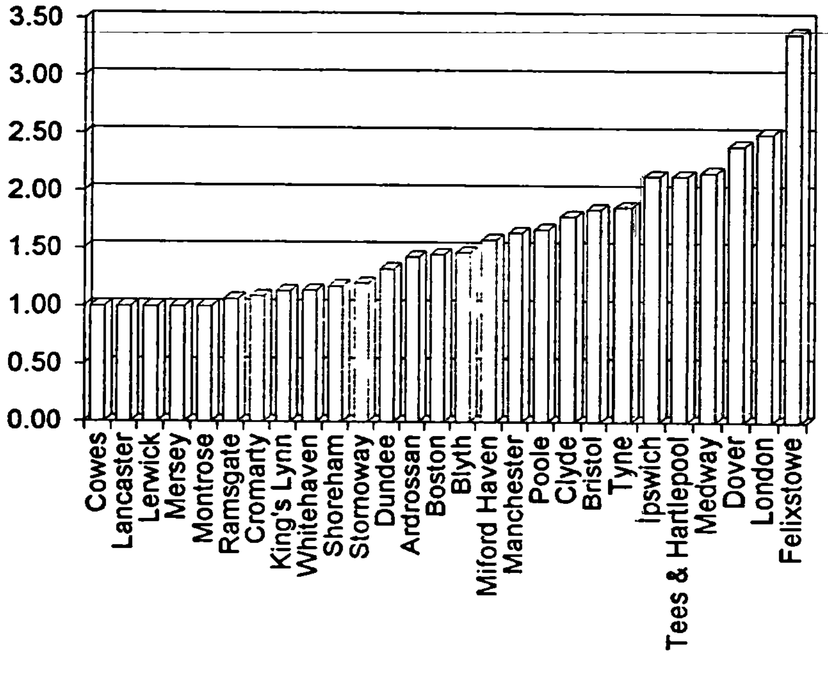
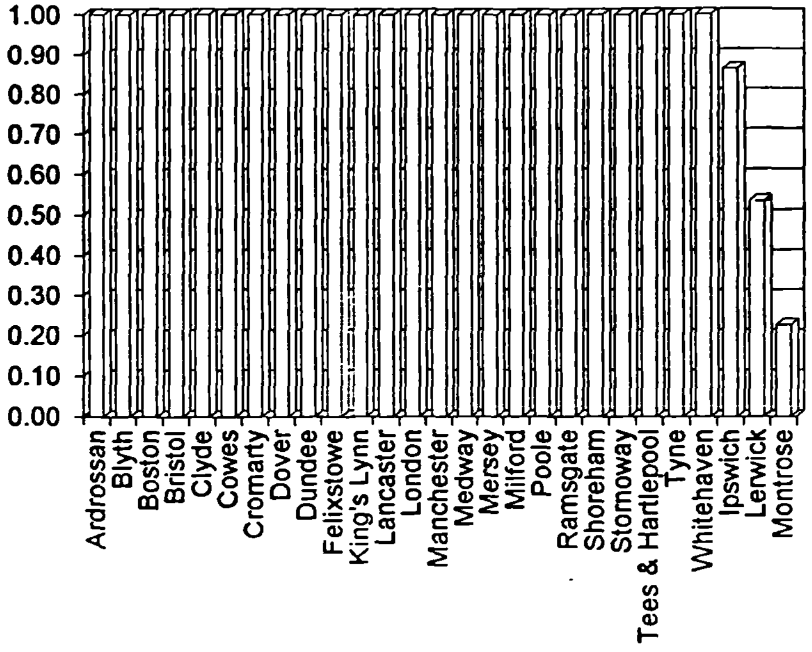


Fig 3.5-3 Scale Efficiency of British Ports 1990
(Non-parametric Measure)

Note: The value of input measure is the fraction of the observed cost in relation to the minimum cost on the frontier for any given input prices; The value of output measure is the multiple of the maximum revenue on the frontier in relation to the observed revenue for any given output prices. For both measures the most efficient score is 1.0.

(a) Input Measure of Congestive Efficiency



(b) Output Measure of Congestive Efficiency

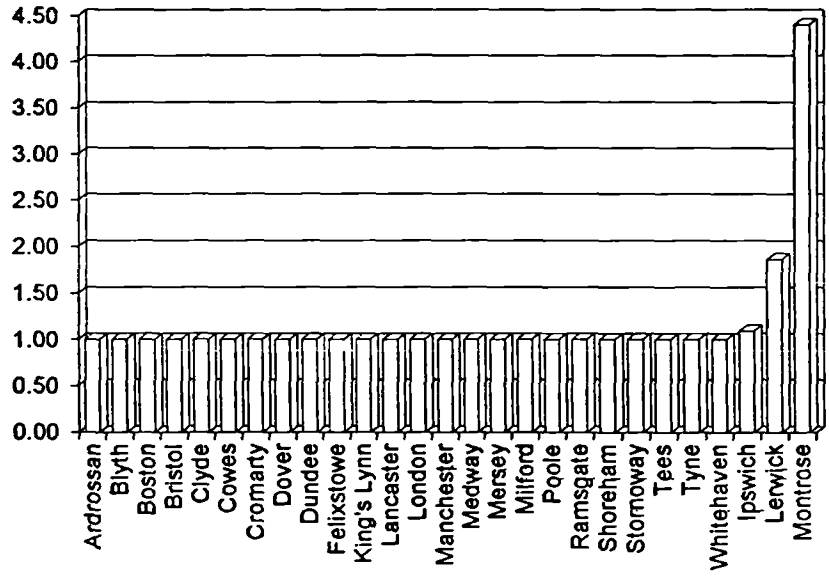


Fig 3.5-4 Congestive Efficiency of British Ports 1990
(Non-parametric Measure)

Note: The value of input measure is the fraction of the observed cost in relation to the minimum cost on the frontier for any given input prices; The value of output measure is the multiple of the maximum revenue on the frontier in relation to the observed revenue for any given output prices. For both measures the most efficient score is 1.0.

In contrast to their PTE and SE scores, most ports in the sample remained congestive efficient. There were only 3 ports that were congestive inefficient including Ipswich, Lerwick and Montrose. Among them only Ipswich was a scheme port. On the whole the industry was free from congestion. The labour scheme was abolished in 1989. But the observation remains true for years before 1989. There is no evidence of congestion in labour input that obstructed output because of the labour scheme.

In the above charts ports are ranked by both input and output measures from the most efficient to the least efficient one. The efficient use of inputs does not necessarily imply that the output vector is produced in an efficient manner. In accordance with a theorem stated by FCL (1985, pp.132) input and output measures of productive efficiency are equivalent if and only if the production technology is homogenous of degree one. Since overall non-price productive efficiency is defined relative to the CRTS technology, the values for OOTE are reciprocal to those for IOTE. Thus IOTE and OOTE suggest exactly the same efficiency rankings as seen in Fig 3.5-2. This is not the case for other notions of efficiency. However, the divergency between input and output measures for PTE, SE and CE is small. In all cases the efficiency rankings suggested by input and output measures are only slightly different.

The efficiency features of the industry in other years are similar to that in 1990, namely, purely productive inefficiency and scale inefficiency are the main causes why British ports depart from the frontier technology.

As noted earlier the problems of input measurement in the data sets may cast doubt on whether the resulting efficiency measures are genuine ones. To see the effect of variable misspecification, we follow Farrell's (1957, pp.270) suggestion to look at the frequency distribution of efficiencies. This is analogous to the measure of goodness of fit in multiple regression analysis. The only difference is that the objective of regression analysis is to explain away all differences while in non-parametric analysis one intends to explain away only non-genuine differences in efficiency. Farrell argued that a plausible shape of genuine efficiency distribution is such as the half-normal, with mode at maximum efficiency while any other shapes (e.g. rectangular, unimodal, the shape with mode at minimum efficiency) may provide a empirical basis for believing the existence of neglected non-managerial factors which are important in explaining productive performance. Fig 3.5-4 shows histograms of components of overall non-price productive efficiency in 1990. The histograms of other years are not shown because they are similar. On Farrell's criterion the distribution of IPTE and ICE might be felt plausible, though they were not particularly well-defined. Farrell's criterion is not applicable to scale efficiency. Unlike purely productive and congestive inefficiency which are private inefficiency, scale inefficiency arising from the departure of the long-run comeptitive equilibrium need not imply managerial inefficiency. By definition there are influences other than managerial quality behind, it is then not surprising that the ISE distribution could be different from the half-normal shape.

Thus it seems that the capital and labour input variables in the analysis have explained the major component while the neglected factors formed only a minor component. Being consistent with this, R-square of the regression equation for the production function consisting of mere capital and labour variables is as high as 96%. This, of course, does not mean that factors like location have no influence on port production. If the locational variable is included in the analysis, the resulting distribution of IPTE and ICE may be more plausible. But in the present context the non-measurement of further factors of production does not seem so important to invalidate the analysis.

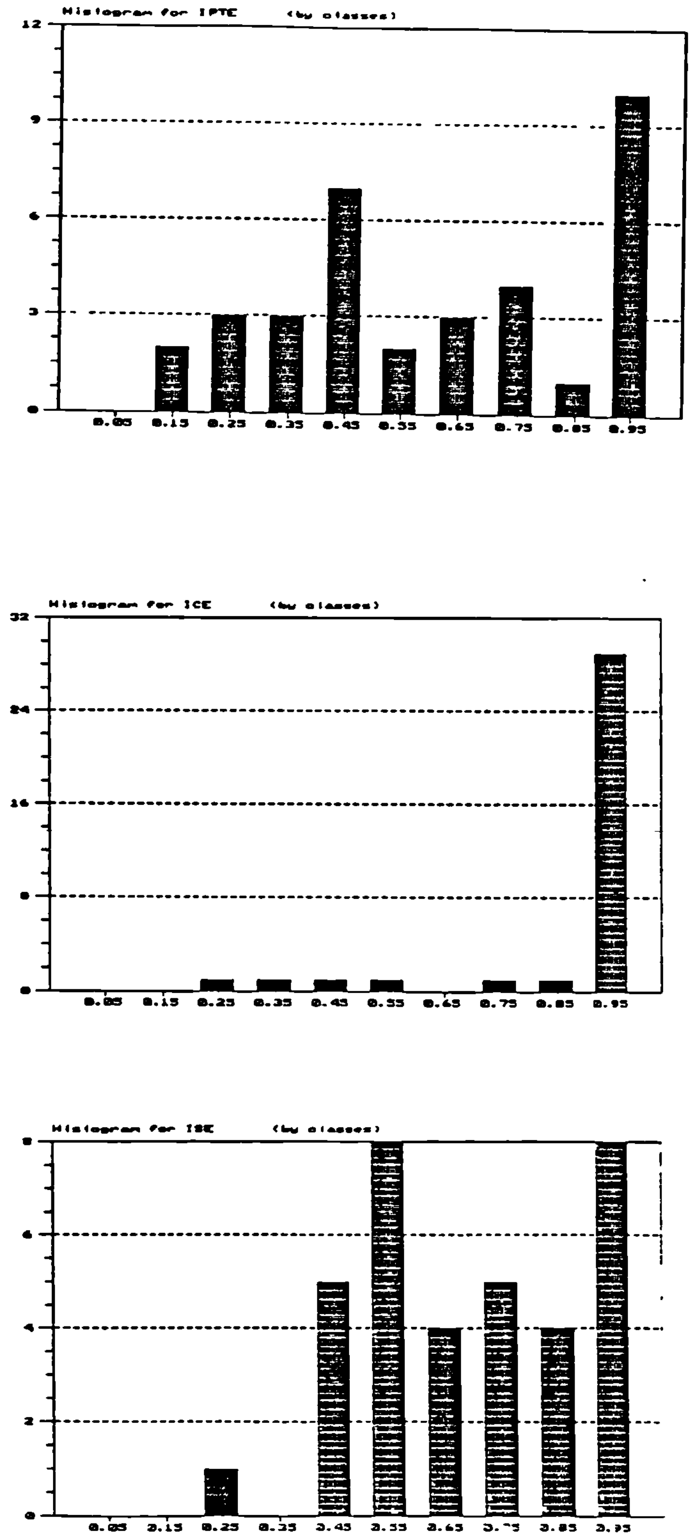


Fig 3.5-5 Distribution of Non-parametric Efficiency in 1990
Note: The histograms for previous years are similar.

Appendix 3.3

Non-parametric Output Efficiency Model

The linear programming problems for output measures of non-price productive efficiency can be formulated in a similar manner to input measures.

The output measure of purely productive efficiency OPTE for the observation (X_0, Y_0) relative to the technology with weak disposability and variable returns to scale can be calculated from the following non-linear programming problem:

$$
\begin{array}{lll}
\text{(A3.3-1)} & \text{Max} & OPTE \\
 & \text{Subject to} & U*Z'*M = Y_0*OPTE \\
 & & Z'*N = V*X_0 \\
 & & \sum_{k=1}^{k} Z_i = 1 \\
 & & 0 < U,\ V \leq 1 \\
 & & Z \geq 0
\end{array}
$$

which can be transformed into the following linear programming problem:

$$
\begin{array}{lll}
\text{(A3.3-2)} & \text{Max} & OPTE \\
 & \text{Subject to} & R'*M = OPTE*Y_0 \\
 & & R'*N = S*X_0 \\
 & & \sum_{k=1}^{k} R_i \leq 1 \\
 & & R \geq 0, \quad 0 < S \leq 1
\end{array}
$$

where $R = U*Z$, $S = U*V$.

Again the restriction $\Sigma R_k \leqslant 1$ is, in practice, $\Sigma R_k = 1$. Otherwise no observed Y or X can have a weight (R_k) equal to unity.

The output measure of weakly productive efficiency (OWTE) for the observation (X_0, Y_0) relative to the technology with strong disposability and variable returns to scale can be calculated from the following linear programming problem:

(A3.3-3) Max OWTE

subject to

$$Z'*M \geqslant OWTE*Y_0$$

$$Z'*N \leqslant X_0$$

$$\sum_{i=1}^{k} Z_i = 1$$

$$Z \geqslant 0$$

The output measure of non-price productive efficiency OOTE for the observation (X_0, Y_0) relative to this technology can be calculated from the following linear programming problem:

(A3.3-4) Max OOTE

Subject to

$$Z'*M \geqslant OOTE*Y_0$$

$$Z'*N \leqslant X_0$$

$$Z \geqslant 0$$

Appendix 3.5

Non-parametric Efficiency Estimates

Table A3.5-1 Input Efficiency of British Ports 1985

PORTS	IOTE[4]	IPTE[5]	IWTE[6]	ICE[7]	ISE[8]	IWTE*[9]
Bristol[1]	0.334	0.567	0.567	1.000	0.589	0.567
Clyde[2]	0.442	0.852	0.852	1.000	0.519	0.852
Dover	0.542	1.000	1.000	1.000	0.542	1.000
Felixstowe	0.373	1.000	0.867	0.867	0.430	0.867
Forth[2]	0.574	1.000	1.000	1.000	0.574	1.000
London[2]	0.446	1.000	1.000	1.000	0.446	1.000
Manchester[2]	0.332	0.607	0.607	1.000	0.546	0.607
Medway[2]	0.496	1.000	1.000	1.000	1.000	0.496
Mersey[2]	0.386	0.951	0.911	0.958	0.424	0.911
Milford Haven	0.762	0.780	0.780	1.000	0.976	0.780
Tees & Hartlepool[2]	0.523	1.000	1.000	1.000	0.532	1.000
Tyne	0.449	0.705	0.705	1.000	0.636	0.705
Aberdeen[3]	0.827	1.000	1.000	1.000	0.827	1.000
Ardrossan	0.383	0.443	0.443	1.000	0.865	0.443
Blyth	0.608	1.000	1.000	1.000	0.608	1.000
Boston[1]	0.502	0.651	0.651	1.000	0.771	0.651
BWB[1] [2] [3]	0.163	0.312	0.312	1.000	0.521	0.312
Cromarty Firth	0.702	0.750	0.727	0.969	0.966	0.702
Ipswich	0.396	0.752	0.752	1.000	0.527	0.752
Lerwick	0.671	0.671	0.671	1.000	1.000	0.671
Poole	0.488	0.612	0.612	1.000	0.797	0.612
Shoreham	0.580	0.582	0.582	1.000	0.996	0.580
Harwich Dock	1.000	1.000	1.000	1.000	1.000	1.000
Milford Dock[2]	0.325	0.329	0.329	1.000	0.987	0.325
Ramsgate	0.713	0.713	0.713	1.000	1.000	0.713

Notes:

[1] Data from the annual report for the year ended on 31 March 1986 while others are for the year ended on 31 December 1985.

[2] Referred to group.

[3] National Dock Labour Board adminstration levies not included in labour costs.

[4] IOTE-input measure of non-price productive efficiency;

[5] IPTE-input measure of purely productive efficiency;

[6] IWTE-input measure of weakly productive efficiency;

[7] ICE-input measure of congestive efficiency;

[8] ISE-input measure of scale efficiency;

[9] IWTE*-input measure of weakly productive efficiency on the star-input correspondence.

Table A3.5-2 Output Efficiency of British Ports 1985

PORTS	OOTE[4]	OPTE[5]	OWTE[6]	OCE[7]	OSE[8]
Bristol[1]	2.994	1.530	1.530	1.000	1.957
Clyde[2]	2.262	1.156	1.156	1.000	1.957
Dover	1.846	1.000	1.000	1.000	1.846
Felixstowe	2.684	1.000	1.110	1.110	2.418
Forth[2]	1.741	1.000	1.000	1.000	1.741
London[2]	2.242	1.000	1.000	1.000	2.242
Manchester[2]	3.016	1.527	1.527	1.000	1.975
Medway[2]	2.017	1.000	1.000	1.000	2.017
Mersey[2]	2.593	1.027	1.027	1.000	2.524
Milford Haven	1.313	1.228	1.228	1.000	1.070
Tees & Hartlepool[2]	1.912	1.000	1.000	1.000	1.912
Tyne	2.229	1.373	1.373	1.000	1.624
Aberdeen[3]	1.209	1.000	1.000	1.000	1.209
Ardrossan	2.680	2.044	2.044	1.000	1.276
Blyth	1.645	1.000	1.000	1.000	1.645
Boston[1]	1.993	1.432	1.432	1.000	1.392
BWB[1] [2] [3]	6.144	2.675	2.676	1.000	2.296
Cromarty Firth	1.424	1.418	1.418	1.000	1.004
Ipswich	2.526	1.296	1.296	1.000	1.949
Lerwick	1.489	1.236	1.296	1.049	1.149
Poole	2.049	1.472	1.472	1.000	1.392
Shoreham	1.724	1.724	1.724	1.000	1.000
Harwich Dock	1.000	1.000	1.000	1.000	1.000
Milford Dock[2]	3.075	3.071	3.071	1.000	1.001
Ramsgate	1.403	1.321	1.321	1.000	1.062

Notes:

[1] Data from the annual report for the year ended on 31 March 1986 while others are for the year ended at 31 December 1985.

[2] Referred to group.

[3] National Dock Labour Board administration levies not included in labour costs.

[4] OOTE-output measure of non-price productive efficiency;

[5] OPTE-output measure of purely productive efficiency;

[6] ICE-input measure of congestive efficiency;

[7] OCE-output measure of congestive efficiency;

[8] OSE-output measure of scale efficiency.

Table A3.5-3 Input Efficiency of British Ports 1986

PORTS	IOTE	IPTE	IWTE	ICE	ISE	IWTE*
Bristol[1]	0.376	0.643	0.643	1.000	0.585	0.643
Clyde[2]	0.565	0.812	0.812	1.000	0.695	0.812
Dover	0.557	1.000	1.000	1.000	0.557	1.000
Felixstowe	0.414	1.000	0.792	0.792	0.523	0.792
Forth[2]	0.591	1.000	1.000	1.000	0.591	1.000
London[2]	0.605	1.000	1.000	1.000	0.605	1.000
Manchester[2]	0.403	0.705	0.705	1.000	0.572	0.705
Medway[2]	0.511	0.769	0.769	1.000	0.665	0.769
Mersey[2]	0.449	0.816	0.816	1.000	0.550	0.816
Milford Haven	0.667	0.668	0.668	1.000	0.998	0.667
Tees & Hartlepool[2]	0.653	1.000	1.000	1.000	0.653	1.000
Tyne	0.537	0.843	0.843	1.000	0.637	0.843
Aberdeen[3]	0.751	1.000	1.000	1.000	0.751	1.000
Ardrossan	0.408	0.430	0.430	1.000	0.948	0.430
Blyth	0.600	0.832	0.832	1.000	0.721	0.832
Boston[1]	0.635	0.703	0.703	1.000	0.903	0.703
BWB[1] [2] [3]	0.190	0.298	0.298	1.000	0.638	0.298
Cromarty Firth	0.556	0.872	0.717	0.822	0.776	0.556
Ipswich	0.563	0.801	0.801	1.000	0.703	0.801
Lerwick	0.638	0.640	0.640	1.000	0.997	0.638
Poole	0.470	0.598	0.598	1.000	0.786	0.598
Shoreham	0.528	0.541	0.541	1.000	0.976	0.528
Harwich Dock	1.000	1.000	1.000	1.000	1.000	1.000
Milford Dock[2]	0.443	0.464	0.464	1.000	0.955	0.443
Ramsgate	0.655	0.657	0.657	1.000	0.998	0.655

Notes:

[1] Data from the annual report for the year ended on 31 March 1987 while others are for the year ended on 31 December 1986.

[2] Referred to group.

[3] National Dock Labour Board administration levies not included in labour costs.

Table A3.5–4 Output Efficiency of British Ports 1986

PORTS	OOTE	OPTE	OWTE	OCE	OSE
Bristol[1]	2.657	1.491	1.491	1.000	1.782
Clyde[2]	1.771	1.213	1.213	1.000	1.460
Dover	1.796	1.000	1.000	1.000	1.796
Felixstowe	2.414	1.000	1.196	1.196	2.018
Forth[2]	1.693	1.000	1.000	1.000	1.693
London[2]	1.653	1.000	1.000	1.000	1.653
Manchester[2]	2.482	1.374	1.374	1.000	1.806
Medway[2]	1.957	1.278	1.278	1.000	1.532
Mersey[2]	2.228	1.124	1.179	1.049	1.889
Milford Haven	1.499	1.364	1.364	1.000	1.099
Tees & Hartlepool[2]	1.532	1.000	1.000	1.000	1.532
Tyne	1.863	1.161	1.161	1.000	1.604
Aberdeen[3]	1.331	1.000	1.000	1.000	1.331
Ardrossan	2.450	2.231	2.231	1.000	1.098
Blyth	1.667	1.165	1.165	1.000	1.431
Boston[1]	1.576	1.334	1.334	1.000	1.181
BWB[1] [2] [3]	5.253	2.858	2.858	1.000	1.838
Cromarty Firth	1.798	1.752	1.752	1.000	1.026
Ipswich	1.775	1.204	1.204	1.000	1.475
Lerwick	1.568	1.216	1.288	1.059	1.217
Poole	2.128	1.480	1.480	1.000	1.438
Shoreham	1.893	1.891	1.891	1.000	1.001
Harwich Dock	1.000	1.000	1.000	1.000	1.000
Milford Dock[2]	2.259	2.247	2.247	1.000	1.005
Ramsgate	1.526	1.380	1.380	1.000	1.106

Notes:

[1] Data from the annual report for the year ended on 31 March 1987 while others are for the year ended on 31 December 1986.

[2] Referred to group.

[3] National Dock Labour Board administration levies not included in labour costs.

Table A3.5-5 Input Efficiency of British Ports 1987

PORTS	IOTE	IPTE	IWTE	ICE	ISE	IWTE*
ABP[2][3]	0.140	1.000	1.000	1.000	0.140	1.000
Bristol	0.109	0.638	0.638	1.000	0.172	0.638
Clyde[2]	0.128	0.871	0.871	1.000	0.147	0.871
Dover	0.176	1.000	1.000	1.000	0.176	1.000
Felixstowe	0.125	0.846	0.846	1.000	0.148	0.846
Forth[2]	0.145	0.875	0.875	1.000	0.166	0.875
London[2]	0.135	0.950	0.950	1.000	0.142	0.950
Manchester[2]	0.125	0.731	0.731	1.000	0.171	0.731
Medway[2]	0.119	0.830	0.830	1.000	0.143	0.830
Mersey[2]	0.113	0.764	0.764	1.000	0.147	0.764
Milford Haven	0.264	0.686	0.686	1.000	0.384	0.686
Tees & Hartlepool[2]	0.136	0.951	0.951	1.000	0.143	0.951
Tyne	0.153	0.897	0.897	1.000	0.171	0.897
Aberdeen[3]	0.254	1.000	1.000	1.000	0.254	1.000
Ardrossan	0.109	0.205	0.205	1.000	0.532	0.205
Blyth	0.118	0.630	0.630	1.000	0.187	0.630
Boston[1]	0.115	0.528	0.528	1.000	0.219	0.528
BWB[1] [2] [3]	0.047	0.265	0.265	1.000	0.177	0.265
Cromarty Firth	0.261	0.331	0.305	0.921	0.855	0.256
Dundee Firth[3]	0.216	0.737	0.737	1.000	0.293	0.737
Ipswich	0.152	0.826	0.826	1.000	0.153	0.991
Lerwick	0.434	0.645	0.645	1.000	0.673	0.645
Poole	0.142	0.631	0.631	1.000	0.225	0.631
Shoreham	0.245	0.433	0.433	1.000	0.565	0.433
Cowes	0.227	1.000	1.000	1.000	0.227	0.227
Harwich Dock	1.000	1.000	1.000	1.000	1.000	1.000
King's Lynn	0.218	0.391	0.388	0.992	0.561	0.218
Lancaster	0.094	0.476	0.476	1.000	0.198	0.094
Montrose	0.137	0.153	0.149	0.974	0.918	0.138
Newlynn	0.357	1.000	1.000	1.000	0.357	0.357
Padstow	0.358	1.000	1.000	1.000	0.358	0.358
Ramsgate	0.336	0.769	0.769	1.000	0.436	0.769
Seaham[3]	0.206	0.777	0.777	1.000	0.266	0.777
Stornoway	0.150	0.312	0.312	1.000	0.480	0.150
Workington[3]	0.976	1.000	1.000	1.000	1.000	1.000
Whitehaven	0.120	0.228	0.228	1.000	0.525	0.120
Yarmouth(IOW)	0.125	0.205	0.202	0.988	0.518	0.105

Notes:

[1] Data from the annual report for the year ended on 31 March 1988 while others are for the year ended on 31 December 1987.

[2] Referred to group.

[3] National Dock Labour Board administration levies not included in labour costs.

Table A3.5–6 Output Efficiency of British Ports 1987

PORTS	OOTE	OPTE	OWTE	OCE	OSE
ABP[2][3]	7.160	1.000	1.000	1.000	1.000
Bristol	9.133	1.489	1.489	1.000	6.132
Clyde[2]	7.740	1.137	1.137	1.000	6.897
Dover	5.686	1.000	1.000	1.000	5.686
Felixstowe	8.006	1.174	1.174	1.000	6.818
Forth[2]	6.875	1.123	1.123	1.000	6.121
London[2]	7.308	1.051	1.051	1.000	7.036
Manchester[2]	8.027	1.322	1.322	1.000	6.073
Medway[2]	8.407	1.194	1.194	1.000	7.040
Mersey[2]	8.873	1.291	1.291	1.000	6.872
Milford Haven	3.794	1.343	1.343	1.000	2.826
Tees & Hartlepool[2]	7.345	1.050	1.050	1.000	6.998
Tyne	6.515	1.107	1.107	1.000	5.884
Aberdeen[3]	3.943	1.000	1.000	1.000	3.934
Ardrossan	9.164	2.132	2.132	1.000	4.299
Blyth	8.510	1.474	1.474	1.000	5.775
Boston[1]	8.660	1.565	1.565	1.000	5.533
BWB[1] [2]	20.22	2.621	3.239	1.236	6.570
Cromarty Firth	3.914	2.938	2.938	1.000	1.332
Dundee Firth[3]	4.609	1.248	1.248	1.000	3.692
Ipswich	6.582	1.000	1.007	1.007	6.537
Lerwick	2.303	1.179	1.249	1.060	1.844
Poole	7.033	1.458	1.458	1.000	4.825
Shoreham	4.125	1.687	1.687	1.000	2.445
Cowes	4.410	1.000	1.000	1.000	1.000
Harwich Dock[2]	1.000	1.000	1.000	1.000	1.000
King's Lynn	4.597	2.962	2.962	1.000	1.552
Lancaster	10.611	8.145	8.145	1.000	1.303
Montrose	7.324	2.928	2.928	1.000	2.502
Newlynn	2.799	1.000	1.000	1.000	2.799
Padstow	2.794	1.000	1.000	1.000	2.794
Ramsgate	2.979	1.227	1.227	1.000	2.428
Seaham[3]	4.846	1.212	1,212	1.000	3.999
Stornoway	6.688	3.179	3.179	1.000	2.104
Workington[3]	1.025	1.000	1.000	1.000	1.025
Whitehaven	8.347	3.172	3.172	1.000	2.631
Yarmouth(IOW)	9.544	4.233	4.233	1.000	2.255

Notes:

[1] Data from the annual report for the year ended on 31 March 1988 while others are for the year ended on 31 December 1987.

[2] Referred to group.

[3] National Dock Labour administration levies not included in labour costs.

Table A3.5-7 Input Efficiency of British Ports 1988

PORTS	IOTE	IPTE	IWTE	ICE	ISE	IWTE*
ABP[2][3]	0.132	1.000	1.000	1.000	0.132	1.000
Bristol	0.091	0.581	0.581	1.000	0.156	0.581
Clyde[2]	0.183	0.597	0.597	1.000	0.172	0.587
Dover	0.135	1.000	1.000	1.000	0.135	1.000
Felixstowe	0.110	0.927	0.803	0.873	0.137	0.803
Forth[2]	0.134	0.846	0.846	1.000	0.158	0.846
London[2]	0.117	0.890	0.853	0.958	0.137	0.853
Manchester[2]	0.102	0.680	0.680	1.000	0.150	0.680
Medway[2]	0.105	0.651	0.651	1.000	0.162	0.651
Mersey[2]	0.102	0.734	0.734	1.000	0.139	0.734
Milford Haven	0.215	0.564	0.564	1.000	0.381	0.564
Tees & Hartlepool[2]	0.113	0.762	0.762	1.000	0.148	0.762
Tyne	0.129	0.725	0.725	1.000	0.178	0.725
Aberdeen[3]	0.197	0.879	0.879	1.000	0.225	0.725
Ardrossan	0.087	0.089	0.088	0.997	0.988	0.087
Blyth	0.091	0.393	0.393	1.000	0.232	0.393
Boston[1]	0.107	0.391	0.391	1.000	0.272	0.391
BWB[1][2]	0.038	0.245	0.245	1.000	0.153	0.245
Cromarty Firth	0.221	0.318	0.298	0.938	0.741	0.221
Dundee Firth[3]	0.175	0.473	0.473	1.000	0.370	0.473
Ipswich	0.100	0.567	0.567	1.000	0.177	0.567
Lerwick	0.300	1.000	0.782	0.782	0.384	0.782
Poole	0.117	0.476	0.476	1.000	0.245	0.476
Shoreham	0.164	0.234	0.234	1.000	0.700	0.234
Cowes	0.147	1.000	1.000	1.000	0.147	0.147
Harwich Dock	1.000	1.000	1.000	1.000	1.000	1.000
King's Lynn	0.093	0.275	0.275	1.000	0.340	0.093
Lancaster	0.081	0.512	0.512	1.000	0.150	0.081
Montrose	0.140	0.182	0.179	0.982	0.780	0.140
Newlynn	0.243	1.000	1.000	1.000	0.243	0.243
Padstow	0.233	1.000	1.000	1.000	0.233	0.233
Ramsgate	0.215	0.632	0.593	0.937	0.362	0.593
Seaham[3]	0.159	0.500	0.500	1.000	0.318	0.500
Stornoway	0.116	0.321	0.321	1.000	0.362	0.116
Workington[3]	1.000	1.000	1.000	1.000	1.000	1.000
Whitehaven	0.105	0.230	0.230	1.000	0.436	0.185
Yarmouth(IOW)	0.065	0.207	0.205	0.990	0.316	0.065

Notes:

[1] Data from annual reports for the year ended on 31 March 1989 while others are for the year ended on 31 December 1988.

[2] Referred to group.

[3] National dock labour board administration levies not included in labour costs.

Table 3.5-8 Output Efficiency of British Ports 1988

PORTS	OOTE	OPTE	OWTE	OCE	OSE
ABP[2][3]	7.599	1.000	1.000	2.119	7.599
Bristol[1]	11.022	1.567	1.567	1.000	7.033
Clyde[2]	9.704	1.576	1.576	1.000	6.518
Dover	7.381	1.000	1.043	1.043	7.080
Felixstowe	9.118	1.037	1.230	1.187	7.413
Forth[2]	7.471	1.143	1.143	1.000	6.538
London[2]	8.573	1.054	1.163	1.103	7.373
Manchester[2]	9.823	1.382	1.382	1.000	7.212
Medway[2]	9.507	1.427	1.427	1.000	6.600
Mersey[2]	9.803	1.328	1.328	1.000	7.382
Milford Haven	4.647	1.443	1.443	1.000	3.220
Tees & Hartlepool[2]	8.846	1.268	1.268	1.000	6.978
Tyne	7.754	1.292	1.292	1.000	6.000
Aberdeen	5.067	1.111	1.111	1.000	4.561
Ardrossan	11.470	2.929	2.929	1.000	3.916
Blyth	10.947	2.037	2.037	1.000	5.373
Boston	9.377	1.923	1.923	1.000	4.876
BWB[1] [2]	26.623	1.654	3.470	2.098	7.672
Cromarty Firth	4.445	2.452	2.495	1.017	1.813
Dundee Firth[3]	5.715	1.549	1.549	1.000	3.691
Ipswich	9.960	1.672	1.672	1.000	5.958
Lerwick	3.329	1.000	1.165	1.165	2.859
Poole	8.562	1.735	1.735	1.000	4.934
Shoreham	6.101	2.017	2.107	1.000	2.895
Cowes	6.805	1.000	1.000	1.000	6.805
Harwich Dock	1.000	1.000	1.000	1.000	1.000
King's Lynn	10.704	4.574	4.574	1.000	2.340
Lancaster	12.397	8.575	8.575	1.000	1.446
Montrose	7.158	2.965	2.965	1.000	2.415
Newlynn	4.109	1.000	1.000	1.000	4.109
Padstow	4.300	1.000	1.000	1.000	4.300
Ramsgate	4.661	1.097	1.341	1.223	3.476
Seaham[3]	6.290	1.567	1.567	1.000	4.014
Stornoway	8.603	4.051	4.051	1.000	2.124
Workington[3]	1.000	1.000	1.000	1.000	1.000
Whitehaven	9.542	3.603	3.603	1.000	2.649
Yarmouth(IOW)	15.471	6.264	6.264	1.000	2.470

Notes:

[1] Data from the annual report for the year ended on 31 March 1989 while others are for the year ended on 31 December 1988.

[2] Referred to group.

[3] National Dock Labour Board administration levies not included in labour costs.

Table A3.5–9 Input Efficiency of British Ports 1989

PORTS	IOTE	IPTE	IWTE	ICE	ISE	IWTE*
ABP[2][3]	0.418	1.000	1.000	1.000	0.418	1.000
Bristol[1]	0.190	0.488	0.488	1.000	0.390	0.488
Clyde[2]	0.329	0.646	0.646	1.000	0.509	0.646
Dover	0.243	1.000	1.000	1.000	0.243	1.000
Felixstowe	0.259	0.613	0.613	1.000	0.423	0.613
Forth[2]	0.387	0.901	0.901	1.000	0.429	0.901
London[2]	0.344	1.000	0.891	0.891	0.385	0.891
Manchester[2]	0.128	1.000	0.590	0.590	0.216	0.590
Medway[2]	0.317	0.718	0.714	0.994	0.444	0.714
Mersey[2]	0.291	0.771	0.702	0.987	0.415	0.702
Milford Haven	0.360	0.762	0.762	1.000	0.473	0.762
Tees & Hartlepool[2]	0.371	0.853	0.853	1.000	0.453	0.853
Tyne	0.339	0.762	0.762	1.000	0.445	0.762
Aberdeen[3]	0.350	0.905	0.905	1.000	0.387	0.905
Ardrossan	0.248	0.287	0.287	1.000	0.867	0.287
Blyth	0.241	0.481	0.481	1.000	0.501	0.481
BWB[1] [2] [3]	0.064	0.230	0.230	1.000	0.280	0.230
Cromarty Firth	0.810	0.901	0.901	1.000	0.899	0.901
Dundee Firth	0.266	0.611	0.611	1.000	0.436	0.611
Ipswich	0.387	1.000	0.937	0.937	0.413	0.937
Lerwick	0.423	1.000	1.000	1.000	0.423	1.000
Poole	0.272	0.581	0.581	1.000	0.469	0.581
Shoreham	0.277	0.505	0.505	1.000	0.548	0.505
Cowes	0.462	0.696	0.696	0.999	0.665	0.462
Harwich Dock	1.000	1.000	1.000	1.000	1.000	1.000
King's Lynn	0.300	0.325	0.325	1.000	0.922	0.325
Montrose	0.195	0.201	0.199	0.994	0.976	0.195
Newlynn	0.326	1.000	1.000	1.000	0.326	0.326
Padstow	1.000	1.000	1.000	1.000	1.000	1.000
Ramsgate	0.254	0.772	0.772	1.000	0.329	0.772
Stornoway	0.272	0.341	0.341	1.000	0.795	0.272
Workington	1.000	1.000	1.000	1.000	1.000	1.000
Whitehaven	0.308	0.319	0.319	1.000	0.967	0.319
Yarmouth(IOW)	0.357	0.357	0.357	1.000	0.998	0.357

Notes:

[1] Data from the annual report for the year ended on 31 March 1990 while others for the year ended on 31 December 1989.

[2] Referred to group.

[3] National Dock Labour Board administration levies not included in labour costs.

Table A3.5–10 Output Efficiency of British Ports 1989

PORTS	OOTE	OPTE	OWTE	OCE	OSE
ABP[2][3]	2.392	1.000	1.000	1.000	2.392
Bristol[1]	5.256	1.904	1.904	1.000	2.761
Clyde[2]	3.038	1.491	1.491	1.000	2.038
Dover	4.109	1.000	1.000	1.000	4.109
Felixstowe	3.858	1.623	1.623	1.000	2.378
Forth[2]	2.585	1.106	1.106	1.000	2.338
London[2]	2.911	1.000	1.114	1.114	2.614
Manchester[2]	7.836	1.000	1.578	1.578	4.966
Medway[2]	3.155	1.302	1.319	1.013	2.392
Mersey[2]	3.435	1.317	1.380	1.048	2.490
Milford Haven	2.777	1.271	1.271	1.000	2.186
Tees & Hartlepool[2]	2.692	1.167	1.167	1.000	2.306
Tyne	2.950	1.292	1.292	1.000	2.284
Aberdeen	2.856	1.089	1.089	1.000	2.622
Ardrossan	4.027	2.340	2.340	1.000	1.721
Blyth	4.156	1.853	1.853	1.000	2.243
BWB[1]	15.53	2.649	3.831	1.446	4.053
Cromarty Firth	1.235	1.105	1.105	1.000	1.118
Dundee Firth[3]	3.752	1.403	1.403	1.000	2.675
Ipswich	2.582	1.000	1.043	1.043	2.476
Lerwick	2.362	1.000	1.000	1.000	2.362
Poole	3.673	1.607	1.607	1.000	2.286
Shoreham	3.613	1.577	1.557	1.000	2.320
Cowes	2.162	2.043	2.043	1.000	1.059
Harwich Dock[2]	1.000	1.000	1.000	1.000	1.000
King's Lynn	3.338	2.854	2.854	1.000	1.170
Montrose	5.135	2.617	2.617	1.000	1.962
Newlynn	3.066	1.000	1.000	1.000	3.066
Padstow	1.000	1.000	1.000	1.000	1.000
Ramsgate	3.942	1.172	1.172	1.000	3.362
Stornoway	3.683	3.205	3.205	1.000	1.149
Workington[3]	1.000	1.000	1.000	1.000	1.000
Whitehaven	3.247	2.835	2.835	1.000	1.146
Yarmouth(IOW)	2.804	2.555	2.555	1.000	1.097

Notes:

[1] Data from the annual report for the year ended on 31 March 1990 while others are for the year ended on 31 December 1989.

[2] Referred to group.

[3] National Dock Labour Board administration levies not included in labour costs.

Table A3.5-11 Input Efficiency for British Ports 1990

PORTS	IOTE	IPTE	ICE	ISE
Bristol[1]	0.236	0.400	1.000	0.590
Clyde[2]	0.433	0.666	1.000	0.650
Dover	0.345	0.509	1.000	0.677
Felixstowe	0.296	1.000	1.000	0.296
London[2]	0.399	1.000	1.000	0.399
Manchester[2]	0.201	0.201	1.000	1.000
Medway[2]	0.344	0.686	1.000	0.487
Mersey[2]	1.000	1.000	1.000	1.000
Milford Haven	0.306	0.442	1.000	0.691
Tees & Hartlepool[2]	0.359	0.742	1.000	0.484
Tyne	0.333	0.517	1.000	0.644
Ardrossan	0.265	0.330	1.000	0.803
Blyth	0.300	0.426	1.000	0.705
Boston[1]	0.340	0.465	1.000	0.731
Cromarty Firth	0.853	0.902	1.000	0.945
Dundee Firth	0.341	0.436	1.000	0.781
Ipswich	0.429	1.000	0.865	0.497
Lerwick	0.336	0.627	0.536	1.000
Poole	0.325	0.477	1.000	0.680
Shoreham	0.322	0.368	1.000	0.901
Cowes	0.607	0.607	1.000	1.000
King's Lynn	0.315	0.315	1.000	0.795
Lancaster	1.000	1.000	1.000	1.000
Montrose	0.227	1.000	0.227	1.000
Ramsgate	0.294	0.304	1.000	0.969
Stornoway	0.290	0.290	1.000	1.000
Whitehaven	0.377	0.377	1.000	1.000

Notes:

[1] Data from the annual report for the year ended on 31 March 1991 while others for the year ended on 31 December 1990.

[2] Referred to group.

Table A3.5–12 Output Efficiency for British Ports 1990

Ports	OOTE	OPTE	OCE	OSE
Bristol[1]	4.237	2.301	1.000	1.841
Clyde[2]	2.310	1.297	1.000	1.781
Dover	2.902	1.448	1.000	2.004
Felixstowe	3.376	1.000	1.000	3.376
London[2]	2.505	1.000	1.000	2.505
Manchester[2]	4.975	3.045	1.000	1.634
Medway[2]	2.996	1.384	1.000	2.165
Mersey[2]	1.000	1.000	1.000	1.000
Milford Haven	3.272	2.080	1.000	1.573
Tees & Hartlepool[2]	2.784	1.304	1.000	2.135
Tyne	3.001	1.611	1.000	1.863
Ardrossan	3.770	2.649	1.000	1.423
Blyth	3.332	2.277	1.000	1.463
Boston[1]	2.942	2.036	1.000	1.445
Cromarty Firth	1.173	1.084	1.000	1.086
Dundee Firth	2.935	2.221	1.000	1.322
Ipswich	2.329	1.000	1.091	2.134
Lerwick	2.976	1.596	1.865	1.000
Poole	3.079	1.848	1.000	1.665
Shoreham	3.016	2.572	1.000	1.173
Cowes	1.647	1.647	1.000	1.000
King's Lynn	3.173	2.809	1.000	1.130
Lancaster	1.000	1.000	1.000	1.000
Montrose	4.406	1.000	4.406	1.000
Ramsgate	3.399	3.325	1.000	1.060
Stornoway	3.453	2.888	1.000	1.196
Whitehaven	2.651	2.337	1.000	1.134

Notes:

[1] Data from the annual report for the year ended on 31 March 1991 while others are for the year ended on 31 December 1990.

[2] Referred to group.

Chapter 4

Productive Efficiency of British Ports
Relative to a Stochastic Frontier

The deterministic approach assumes that it is meaningful to define exactly the maximal possible output level given inputs, or the minimal possible input level given outputs, and hence uses a purely one-side error. Although it is argued that deterministic frontiers are consistent with economic theory, their chief disadvantage is that they are bound to be contaminated by statistical noise. In this chapter we intend to estimate price-independent productive efficiency, both overall and by components, of British ports relative to a stochastic rather than a deterministic frontier. This requires the stochastic frontier to be modelled using a less restrictive functional form, and measures of various efficiency notions to be constructed in a parametric framework.

A brief critical review of the development of the parametric approach is provided in section 4.1. Section 4.2 outlines the methodological framework for various notions of productive efficiency to be defined in terms of parametric measures. Section 4.3 discusses the specification and estimation of the stochastic frontier production function model for efficiency measurement. Section 4.4 applies the model to a panel of input and output data for British ports from 1983 to 1990. In Section 4.3 and 4.4 the analysis treats the pooled data as it were cross-sectional and it is assumed that inefficiency is uncorrelated with regressors and distributed as half-normal or exponential. By taking the qualitative advantages of panel data these structures are tested in Section 4.5. The variety of different methods for panel data analysis are applied to the same data set. However, the efficiency distribution derived from the panel data analysis is not found more plausible than that derived from the cross-sectional data analysis on Farrell's criterion. Production frontiers with different technological characteristics are estimated, against which efficiency estimates are derived for British ports. These parametric estimates are compared with the non-parametric estimates. Although parametric measures suggest a smaller magnitude of inefficiency than non-parametric measures, the two measures are in agreement that the main sources of non-price productive inefficiency in the industry are purely productive inefficiency (either X-inefficiency or technical inefficiency) and scale inefficiency.

4.1 The Parametric Approach

The alternative to the non-parametric approach is to specify a parametric representation of technology. It should be noted that a frontier model can be either a single equation (e.g. production, cost, revenue, distance function) or a system of equations (e.g. cost system). In what follows only a single-equation model of the frontier production function is considered. As a matter of fact a production function written as

$$(4.1\text{-}1) \qquad Y = f(X,\beta)$$

represents a single-output reference technology in the context of revenue maximisation, where Y denotes the output, X denotes a vector of inputs and β denotes the input coefficients. This approach was also proposed by Farrell, but first implemented by Aigner and Chu (1968) in order to generalise Farrell's non-parametric approach. By applying the techniques of linear and quadratic programming to cross-section data of firms, Aigner and Chu established the frontier function by controlling the disturbance term to be of one sign. For a linear programming formulation the objective function appears as the sum of such disturbances (a linear loss function), while for the quadratic programming the criterion is a minimum of the sum of squared residuals (a quadratic loss function). The parametric approach was considered to be superior to its non-parametric counterpart as no presumptions need to be made about returns to scale for the production function, as was necessary in Farrell's work. But as argued by Aigner and Chu themselves, the estimation potential of these techniques is reduced to some extent by a lack of available statistical inference procedures, since no efficiency differences between the units are assumed to be generated by an explicit efficiency distribution.

In an attempt to give them a statistical basis, Afriat (1972) assumed that the error term is a result of technical inefficiency and is distributed as a two part-parameter beta distribution while Richmond (1974) assigned a gamma distribution to the error term. The frontier production function can then be estimated by the maximum likelihood method (ML), or by the corrected ordinary least square (COLS) method which uses the mean of the disturbance term to correct the constant.

Schmidt (1976) has proved that the assumption that the error term has an exponential distribution leads to the linear programming approach, while the assumption that the error term has a half-normal distribution leads to the quadratic programming technique. Therefore Aigner and Chu's estimates can be viewed as ML estimates under a particular error specification.

Unfortunately the regularity conditions for the application of ML are violated as far as most error specifications are concerned. Since $Y \leqslant f(X,\beta)$, the range of the random variable depends on the parameters to be estimated. One way round this is to search for a certain error distribution which satisfies the regularity conditions (e.g. gamma distribution, see Greene, 1980). The alternative is to adopt the COLS method.

Like non-parametric frontier models, the early parametric frontier models are deterministic in the sense that all firms share a common fixed family of frontiers. This is of course unreasonable and ignores the real possibility that the firm's observed performance may be affected by exogenous (random shock) as well as endogenous (inefficiency) factors. In addition to random shocks there are possibilities of specification and measurement error. To lump all these things, favourable and unfavourable, under or beyond the control of the production unit, together into a single disturbance term and label the mixture as inefficiency is questionable. As a result the parametric representation of the reference technology is highly sensitive to extreme outliers. This can cause an over- or under-estimation of the true extent of inefficiency.

The parametric approach was proposed as a superior alternative to the non-parametric approach as the early non-parametric models require restrictive assumptions. After the non-parametric models had been generalised by later development, the parametric approach lost much of its attraction until stochastic frontier models were proposed. Aigner, Lovell and Schmidt (1977), and Meeusen and van den Broeck (1977) constructed a more reasonable error structure than a purely one-sided one. To simplify discussion they considered a linear model for the frontier production function:

$$(4.1\text{-}2) \qquad Y_i = \alpha + X_i'\beta + Z_i \qquad i = 1,2,\ldots,N$$

Here i indexes firms. α is constant, which is the first element of the parameter vector β in Eq(4.1-1). Their disturbance term Z consists of two parts

$$(4.1\text{-}3) \qquad Z_i = V_i - U_i$$

The error component V_i represents a symmetric disturbance and permits random variation of production across production units due to the effects of measurement and specification error, and of exogenous shocks beyond the control of the production unit. The error component $U_i \geq 0$ is one-sided and represents price-independent productive inefficiency. Recall that the reason why we term U non-price productive inefficiency rather than technical inefficiency was made clear in section 3.1 of chapter 3: the departure from the frontier is hypothesized as both X-inefficiency and technical inefficiency. The deviation of an observation from the deterministic kernel of the stochastic production function arises from two sources: a symmetric random variation of the deterministic kernel ($\alpha + X_i'\beta$) across observations captured by the component V_i, and asymmetric variation captured by the component U_i.

Non-price productive inefficiency should then be measured by the ratio

$$(4.1\text{-}4) \qquad Y_i/(\alpha + X_i'\beta + V_i)$$

relative to the stochastic frontier $f(X;\beta)+V$ rather than by the ratio

$$(4.1\text{-}5) \qquad Y_i/(\alpha + X_i'\beta)$$

relative to the deterministic kernel of the stochastic frontier $f(X;\beta)$.

Both the ML and COLS can be used to provide consistent estimates of the parameters. The ML is asymptotically efficient, but it needs the distributional assumption for inefficiency.

The problem of early stochastic frontier models is that they provide estimates of productive efficiency only in terms of sample mean, rather than for each observation, since V_i is unobservable. Fortunately, Jondrow, Lovell, Materow and Schmidt (1982) have shown how to extract estimates of productive efficiency for each observation in the sample, by decomposing the composed error term into its components. This is done by calculating the conditional distribution of U given Z, and estimates of U_i for each observation are provided by the mean or mode of the conditional distribution of U_i given Z_i truncated at zero.

Nevertheless the estimate of the firms' inefficiency levels is not consistent, as it contains statistical noise as well as productive efficiency (Schmidt and Sickles, 1984). In addition, stochastic frontier models suffer from two other difficulties. One is the requirement of specific assumptions about productive efficiency and statistical noise. These assumptions can be avoided by using the COLS if one wishes to estimate the frontier function only, but will be necessary if one needs to separate productive efficiency from statistical noise for each observation. The other is the requirement of the assumption of non-independence of regressors and productive inefficiency.

Over the last ten years one further development in the frontier field is estimation techniques for the use of panel data. The first paper to develop techniques to use panel data to estimate frontier functions, was Pitt and Lee (1981), but their ML approach fails to take qualitative advantages of panel data and requires strong assumptions exactly as for the cross-sectional model. Schmidt and Sickles (1984) suggested a number of desirable features of the techniques (the Within estimator, the generalised least square (GLS) estimator and the Hausman-Taylor estimator for panel data analysis. First of all, consistent estimates of the productive efficiency of a firm can be obtained as the number of time periods tends to infinity. This is so because adding more observations on the same firm yields information not attainable by adding more firms. Secondly, unlike the techniques for cross-sectional analysis which draws evidence of inefficiency in skewness, the technique of panel data analysis draws evidence of inefficiency in constancy over time. As a result, strong distributional assumptions are not necessary when panel data are available. Finally, the parameters and the firms' efficiency levels can be estimated without assuming non-independence of regressors and productive inefficiency.

It should be noted that the desirable properties of the techniques for panel data analysis are not unconditional. Suppose that the frontier production function is of the form

$$(4.1\text{-}6) \qquad Y_{it} = \alpha + X_{it}'\beta + V_{it} - U_i$$
$$i = 1,2,\ldots,N, \quad t = 1,2,\ldots,T.$$

where i indexes firms and t indexes time periods. The Within estimator which treats the effects U_i as fixed and relies neither on their uncorrelatedness with the regressors nor on the distribution of these effects. The Within estimate of β is consistent as either N or $T \to \infty$. But consistency of the individual estimated intercepts $(\alpha - U_i)$ requires $T \to \infty$ and consistent separation of the overall intercept

(α) from the one-sided individual effects (U_i) requires $N \rightarrow \infty$. The GLS estimator treats the effects U_i as random and requires the assumption that they are uncorrelated with the regressors but not the assumption about the distribution of the effects. Consistent estimation of productive inefficiencies by the GLS also requires both $N \rightarrow \infty$ and $T \rightarrow \infty$. Under the assumption of uncorrelatedness of effects and regressors the GLS is more efficient. If N is large and T is small, the GLS has its appeal as consistent estimation of σ_u^2 requires $N \rightarrow \infty$. Another advantage of the GLS over the within estimator is its ability to include time-invariant regressors which is impossible with the latter. If only a subset of regressors are assumed to be correlated with the effects, Schmidt and Sickles suggested use of the Hausman-Taylor (1981) estimator, which has the same properties as for the GLS.

While the stochastic approach can handle statistical noise, its chief disadvantage *vis-a-vis* non-parametric models remains the imposition of a restrictive function form for technology and an explicit distribution for the inefficiency. Although the techniques of panel data analysis enables us to relax this assumption, this approach requires another assumption, that firm inefficiency is invariant with time, since the techniques of panel data analysis are focused on cross-sectional variation. Further efforts need to be made in this direction. On the other hand, the problem of restrictive functional form for technology remains almost untouched. The most widely-used functional form is Cobb-Douglas, which is homogenous and monotonic. Firstly for the Cobb-Douglas function the elasticity of scale (returns to scale) is fixed. In other words if the elasticity of scale is 'n' for one level of output and one factor combination, then it will be 'n' for all levels of output and all factor combinations. The resultant long-run average cost curve is either continuously rising, or constant, or continuously falling rather than 'U'-shaped. Secondly the monotonicity of technology requires a positive marginal product of inputs. That is equivalent to assuming that the technology is free from congestion. The reference technology represented by the Cobb-Douglas function is restrictive, so that congestive efficiency is missing and scale efficiency is meaningless. The inefficiency estimates derived from the Cobb–Douglas technology are crude, and the information about the frontier and the relative efficiency of firms yields less precise policy implications than in non–parametric models, in which a variety of efficiency notions are measurable.

We are now in a position to consider less restrictive structures for technology in order to restore the missing notions of productive efficiency.

4.2 Parametric Measurement of Productive Efficiency

Recall that in the non-parametric framework the less restrictive production structure is represented by the subsets of the output and input correspondence which satisfy weak axioms L.1–L.5, or P.1–P.5. Apparently a production function representing the less restrictive technology can then be defined in terms of input and output correspondences (Shephard, 1953), i.e.

$$(4.2\text{-}1)\quad f(X) = \max\{Y: X \in L(Y)\} = \max\{Y: Y \in P(X)\}$$

Shephard has shown that if the production technology satisfies (L.1–L.5) or (P.1–P.5), then the production function (4.2–1) has the following properties

f.1 $f: R(n)_+ \to R_+$, $f(0)=0$,

f.2 f is upper semi-continuous,

f.3 $f(\lambda X) \geq f(X)$ for $\lambda \geq 1$.

A production function which satisfies only f.1–f.3, imposes a less restrictive structure on technology than is normally the case. Particularly, as f.3 states, proportional increases in inputs do not decrease outputs. The axiom is referred to as weak disposability of inputs. A stronger axiom than f.3 obtained by imposing strong disposability of inputs is

f.3.S $f(X') \geq f(X)$ for $X' \geq X$.

By f.3.S an increase in inputs, including but not limited to a proportional increase, cannot lead to a reduction in output. While strong disposability of inputs implies a positive marginal product, weak disposability of inputs requires that the marginal product is unconstrained in sign. If inputs are strongly disposable they are also weakly disposable. But the converse is not true. The strong disposability axiom excludes congestion in the technology. With the weak disposability axiom the possibility of congestion in technology is not ruled out, and one can define congestion efficiency in this less restrictive framework.

Definition 1: A technology represented by f(X) satisfying only f.1–f.3 is congestive efficient at $X=X_0$ if $\partial f/\partial X \geqslant 0$ at $X=X_0$ and congestive inefficient at $X=X_0$ if $\partial f/\partial X < 0$ at $X=X_0$.

Secondly, the technology which satisfies only f.1–f.3 does not restrict the variability of the elasticity of scale with the level of output and factor combination. It is then meaningful to define scale efficiency.

Definition 2: A technology represented by f(X) satisfying only f.1–f.3 is scale efficient at $X=X_0$ if the elasticity of scale $(df/Y)/(dX/X) = 1$ (constant returns to scale) at $X=X_0$ or scale inefficient at $X=X_0$ if $(df/Y)/(dX/X) \neq 1$ at $X=X_0$ due to either $(df/Y)/(dX/X) \geqslant 1$ (increasing returns to scale) or $(df/Y)/(dX/X) \leqslant 1$ (decreasing returns to scale).

As far as computational methods are concerned, one may first construct and estimate the three reference technologies separately. The function form for the weakly disposable technology (with variable scale elasticity and weak disposability) is an f(X) which satisfies no more than f.1–f.3. The functional form for the strongly disposable technology (with variable scale elasticity and strong disposability) is obtained by imposing a non-negative marginal product restriction on f(X). For the long-run competitive equilibrium technology (with constant returns to scale and strongly disposability) a further restriction is that f(X) be homogenous of degree one. As with the non-parametric approach the three primary efficiency measures (purely productive efficiency PTE, weakly productive efficiency WTE and overall non–price productive efficiency OTE) can be obtained against the three technologies respectively and the measures of congestion efficiency and scale efficiency can be derived from the three primary measures accordingly. In stochastic models, each primary measure corresponds to an one–sided error term U associated with a frontier technology which has relevant properties of returns to scale and disposability. Thus the estimate of U derived from the long–run competitive equilibrium frontier technology gives the value of overall non–price productive inefficiency; the estimate of U derived from the strongly disposable frontier technology gives the value of weakly productive inefficiency; the estimate of U derived from the weakly disposable frontier gives the estimate of purely productive inefficiency. Meaningfully, it should be the case that the value of overall non–price productive inefficiency is not less than the value of weakly productive inefficiency, which is in turn not less than the value of purely productive inefficiency, since the production possibilities set shrinks as a less restrictive technology is applied and the departure from the less restrictive technology tends to be smaller for a particular observation. This is always the case when the frontiers are deterministic. But if the frontiers are stochastic there is no guarantee that the deterministic kernel of the estimated stochastic production frontier generated by the long–run competitive equilibrium technology lies above that generated by the strongly disposable technology, which in turn lies above that generated by the weakly disposable technology. In consequence the inequality does not necessarily hold in terms of estimated one–sided terms.

To escape from this apparent impasse, an alternative procedure is used. We first estimate the stochastic frontier associated with the weakly disposable technology (the least restrictive one) and extract estimates of purely productive inefficiency accordingly. We then derive the two restrictive technologies (the strongly disposable technology and the long–run competitive equilibrium technology) from the deterministic kernel of the estimated stochastic frontier, and estimate congestive inefficiency and scale inefficiency against the technologies derived. The treatment is illustrated diagramatically as follows.

Suppose that the deterministic kernel of the stochastic frontier, f(X), which represents a weakly disposable reference technology, has already been estimated (the procedure will be discussed in the next section). Consider first how to derive the strongly disposable technology and construct a measure of congestive efficiency. Since the technology does not rule out the possibility of congestion in inputs, it is then possible that output will be obstructed by increases in one input while other inputs are kept fixed. Fig 4.2-1 illustrates such a situation in a case of two inputs (X_1,X_2) where the first input X_1 causes congestion at A in the congested region of the weakly disposable technology $f(X_1,X_2)$. To evaluate the degree of congestive efficiency for the point A, we vary X_1 while the second input X_2 is fixed at the observed level $(X_2=X_{2_A})$. The graph in Fig 4.2-1 is obtained by cutting the surface of $f(X_1,X_2)$ with the vertical plane $X=X_{2_A}$. It represents a partial function of $f(X_1,X_2)$ denoted by $f(X_1,X_{2_A})$. Given X_2, the factor ratio (X_1/X_2) increases with X_1. The maximum level of output is obtained at the factor ratio given by X_{1_M}/X_{2_A}. Before the optimal ratio is reached (when $X_1<X_{1_M}$), output increases with increases in X_1. Beyond the optimal ratio (when $X_1>X_{1_M}$), however, output declines with increases of X_1. The declining portion of the graph represents the range of output obstructed by congestion in X_1.

By *Definition 1*, a straightforward way to detect congestive inefficiency is to evaluate the sign of the marginal product at observed input values. If the marginal product of the input of interest is non-negative, this implies the use of the input is free from congestion. If, however, the sign of marginal product is negative, then the firm involved is congestive inefficient. To construct the congestive measure, a congestion-free (strongly disposable) technology has to be derived from the possibly congested (weakly disposable) technology $f(X_1,X_2)$. For the congestively inefficient observation A, the strongly disposable technology can be constructed as

$$(4.2\text{-}2)\quad Y = \begin{cases} f(X_1, X_{2A}) & 0 < X_1 < X_{1M} \\ f(X_{1M}, X_{2A}) & X_1 > X_{1M} \end{cases}$$

which consists of the increasing portion of the graph and the line segment MB. Given the actual usage of inputs (X_{1A}, X_{2A}), the maximum possible level output obtainable from the strongly disposable (congestion-free) technology would be Y_B. This output level is, however, not obtainable from the weakly disposable technology, but, by disposing of $X_{1A}-X_{1M}$ units of the first input, the output level is obtainable. The reference point B is efficient in the weak sense. Thus for the congestively inefficient observation A, a possible measure of congestion can be constructed as the ratio of $[f(X_{1M},X_{2A})- f(X_{1A},X_{2A})]$ in relation to $f(X_{1M},X_{2A})$, i.e. the ratio of $(Y_B-Y_A)/Y_B$.

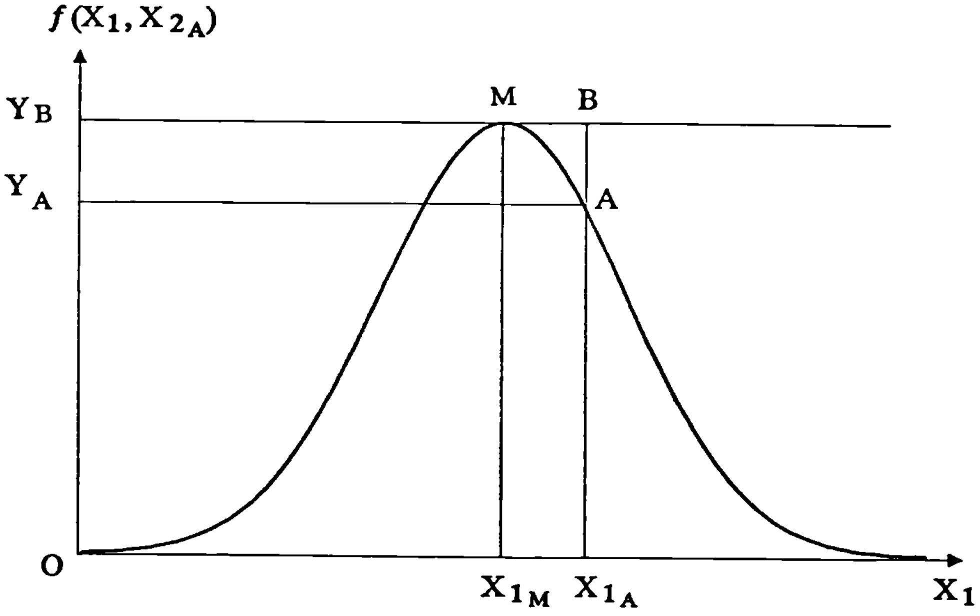


Fig 4.2–1 Parametric Measure of Congestive Inefficiency

To measure scale efficiency, consider Fig 4.2–2, where again $f(X_1,X_2)$ is the deterministic kernel of the estimated stochastic production function in the case of two inputs. For simplicity, assume that there is no congestive inefficiency so that the weakly disposable technology $f(X_1,X_2)$ coincides with the strongly disposable technology. In the presence of congestive inefficiency, one needs to replace the weakly disposable technology with a strongly disposable technology, which can be derived following the procedure described above. To evaluate the degree of scale efficiency for A on the strongly disposable technology, we vary operational scale while the factor ratio is fixed at the level given by A (X_{1A}/X_{2A}). The graph in Fig 4.2-2 is obtained by cutting the surface of $f(X_1,X_2)$ with a vertical plane through the origin along the ray of the factor ratio X_{1A}/X_{2A}. This is a two dimensional section of the production possibility set which indicates the deterministic maximum possible output for the given factor proportion X_{1A}/X_{2A} at the different levels of operational scale. While the vertical axis represents output Y, the horizontal axis represents the level of input X $(\mu X_{1A},\mu X_{2A})$ at varying operational scale μ for the given factor ratio.

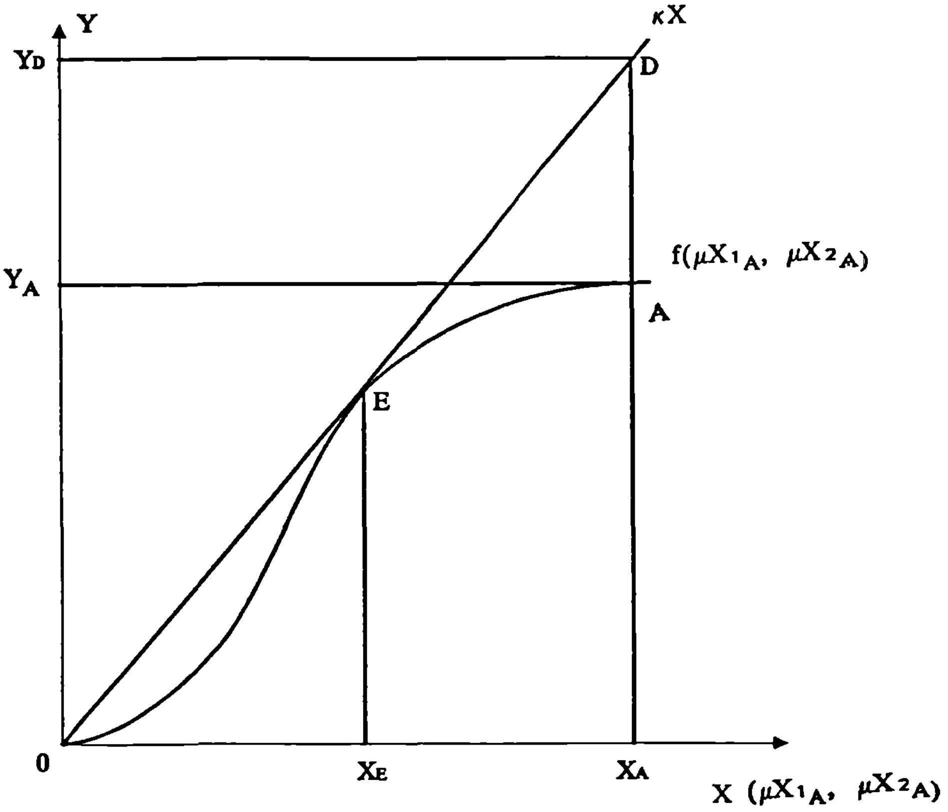


Fig 4.2-2 Parametric Measure of Scale Inefficiency

The strongly disposable technology $f(X_1,X_2)$ allows for increasing, constant and decreasing returns to scale. By *Definition 2*, the technology is scale inefficient either when increasing returns to scale prevail ($0<X<X_E$) or when decreasing returns to scale prevail ($X>X_E$). To construct a scale efficiency measure, one needs to derive the long-run competitive equilibrium (CRTS and strongly disposable) technology from $f(X_1,X_2)$. The point E on $f(X_1,X_2)$, where constant returns to scale prevail, represents the production possibility that maximises the 'average productivity' for the given factor ratio and is scale efficient. By connecting the origin and the point E, one obtains the CRTS and strongly disposable technology, which can be defined as

$$(4.2\text{-}3) \qquad Y = \kappa X$$

where κ is the maximum 'average productivity' and $\kappa=Y/X$ when the elasticity of scale $(dY/Y)/(dX/X) = 1$. A scale other than X_E would be non-optimal for the same factor ratio. As far as the observation A is concerned, the maximum possible output obtainable, for the factor ratio and the input level implied by X_A, from the CRTS and strongly disposable technology is given by Y_D. The shortfall of output due to sub-optimal scale operation is given by Y_D-Y_A. The scale efficiency for A can then be measured by the ratio of $(Y_D-Y_A)/Y_D$.

4.3 The Stochastic Model of the Production Frontier

As argued above the specification of a less restrictive structure for the frontier technology enables us to define productive efficiency in a more meaningful and systematic way. Efficiency estimation in this framework involves two steps:

(1) to specify and estimate the stochastic model of the weakly disposable frontier technology f(X) and then extract estimates for the one-sided disturbance term, i.e. purely productive inefficiency.

(2) once the unrestrictive technology has been estimated, the restrictive technologies, i.e. the strongly disposable technology given in Eq(4.2-2) and the CRTS and strongly disposable technology given in Eq(4.2-3) can be derived from f(X). Estimates of congestive efficiency and scale efficiency can then be obtained against the restrictive technologies accordingly.

In the previous section we assumed that the unrestrictive technology was given and outlined the procedure of the second step. In this section we consider the procedure of the first step. The functional form chosen to model the unrestrictive technology should be flexible enough to allow for variable scale elasticity and weak disposability. One such flexible functional form is the Translog Production Function. For the two-input case, where X_1 denotes labour and X_2 denotes capital as before, the function is

$$(4.3\text{-}1)\quad \log Y_i = \log\gamma_0 + \alpha_1 \log X_{1i} + \beta_1 \log X_{2i} + \alpha_2(\log X_{1i})^2 + \beta_2(\log X_{2i})^2 + \gamma_1 \log X_{1i} \log X_{2i}$$

Note that no presumptions regarding disposability and scale elasticity are imposed by this function on the structure of production technology. The elasticity of scale (Ψ_S) for the function is given by

$$(4.3\text{-}2)\quad \Psi_S = \alpha_1+\beta_1+(2\alpha_2+\gamma_1)\log X1_i+(2\beta_2+\gamma_1)\log X2_i$$

From this it is clear that in general the elasticity of scale changes with factor proportions and with the level of production. Thus the long-run average cost curve can take the 'U-shape' so often assumed for it in the theory of firms.

The marginal product of labour (MPL) and the marginal product of capital (MPC) are given by

$$(4.3\text{-}3)\quad \text{MPL} = (Y_i/X1_i)(\alpha_1+2\alpha_2\log X1_i+\gamma_1\log X2_i)$$

and

$$(4.3\text{-}4)\quad \text{MPC} = (Y_i/X2_i)(\beta_1+2\beta_2\log X2_i+\gamma_1\log X1_i)$$

respectively. Since MPL and MPC are unrestricted in sign, the translog technology is not free from congestion. Therefore the translog function can be used to model the weakly disposable production technology.

The translog model is a generalisation of a Cobb-Douglas model or of a Taylor series approximation of a CES model. Thus a further advantage of the translog model is that it provides a testable functional form, which enables us to choose an appropriate specification for the deterministic part of the frontier production function.

While Eq(4.3-1) is the deterministic part of the stochastic translog frontier model, the whole model is given by,

$$\begin{aligned}(4.3\text{-}5)\quad \log Y_i = {} & \log\gamma_0+\alpha_1\log X1_i+\beta_1\log X2_i+\alpha_2(\log X1_i)^2+\beta_2(\log X2_i)^2\\ & +\gamma_1\log X1_i\log X2_i\\ & + V_i-U_i\end{aligned}$$

where in the stochastic part the symmetric error component V permits the production function to vary across ports and captures exogenous influences, measurement and specification error. Thus the stochastic translog frontier, i.e.

$$(4.3\text{-}6)\quad \log Y_i=\log\gamma_0+\alpha_1\log X1_i+\beta_1\log X2_i+\alpha_2(\log X1_i)^2+\beta_2(\log X2_i)^2 +\gamma_1\log X1_i\log X2_i+V_i$$

is unique for each observation. The one-sided error component $U \geq 0$ relative to the stochastic translog frontier represents purely productive inefficiency. Given the logarithmic form, the value of U_i is approximately the shortfall of output below the stochastic frontier in percentage terms. Thus EXP($-U_i$) is purely productive efficiency as a percentage.

The symmetric error component V is identically and independently distributed to $N(0,\sigma_V^2)$. Two possible specifications are considered for the one-sided error component:

(1) U_i is half-normal, i.e. $|U_i| \sim N\ (0,\sigma_u^2)$

$$(4.3\text{-}7)\qquad f(U_i) = (2/\pi)^{1/2}\, e^{-1/2(U_i/\sigma_u)^2}$$

$$E(U_i) = \sigma\varphi(0)/\Phi(0) = (2/\pi)^{1/2}\,\sigma_u$$

$$\mathrm{Var}(U_i) = (1-2/\pi)\,\sigma_u^2$$

where $\sigma^2 = \sigma_u^2 + \sigma_v^2$, and $\varphi(.)$ and $\Phi(.)$ denote the standard normal density and distribution functions;

(2) U is exponential, i.e.

$$(4.3\text{-}8)\qquad f(U_i) = \theta e^{-\theta U_i}$$

$$E(U_i) = 1/\theta$$

$$\mathrm{Var}(Ui) = (1/\theta\ )^2$$

Stochastic frontier models can be estimated in several ways. The most commonly-used estimator is the ML method. Given cross-sectional data, the log-likelihood function is given by

$$(4.3\text{-}9)\quad \Sigma_i \ln L_i = -\ln\sigma - (1/2)\ln(2/\pi) - (Z_i/\sigma)^2 + \ln\Phi[-Z_i\lambda/\sigma]$$

for half-normal error specification, and

$$(4.3\text{-}10)\quad \Sigma_i \ln L_i = \ln\theta + (1/2)\theta^2\sigma_V^2 + \theta Z_i + \ln\Phi[-(Z_i/\sigma_V + \theta\sigma_V)]$$

for exponential error specification. In both cases Z_i is the composed disturbance and $Z_i = V_i - U_i$.

An alternative estimator is the corrected ordinary least square (COLS) method. Except for the constant term, the COLS is exactly the same as the OLS. The bias of the constant term can be corrected by adding to the OLS estimated constant term the mean of Z_i, i.e. E(U) in Eq(4.3-7) if U_i is half-normal, or $E(U_i)$ in Eq(4.3-8) if U_i is exponential. The variances σ_V^2 and σ_U^2 can be consistently estimated from the second and the third moments of OLS residuals.

Both the COLS and ML are consistent estimators for the model Eq(4.3-5). The main advantage of the COLS is that it is easier to compute than the ML estimator. Its main disadvantage is that it is asymptotically inefficient as compared with the ML. Now that computers do most of the work the extra complexity of calculation involved in ML estimation is less important. However, Olson, Schmidt and Waldman (1980) found that, based on their Monte Carlo experiments with a constant term only model, the COLS method is more efficient than the ML method in terms of means square error for sample size below 200. We have also conducted a few experiments with a Cobb-Douglas model consisting of a constant and two regressors. To reduce sampling error in Monte Carlo results, our experiments were based on more replications (200 times). The results are shown in Table 4.3-1 for sample points N=30, 50, 100, 150, 200 and the variance ratio $\lambda = \sigma_U^2/\sigma_V^2 = 1$ in each case. Our results confirmed better performance of the COLS in small samples, but the difference is not as large as suggested by Olson, *et al.*

While the COLS is as (MES) efficient as the ML in terms of coefficient (β) estimates, the former outperforms the latter in terms of the variance ($\sigma^2=\sigma_u^2+\sigma_v^2$) estimate. In addition, the sample size, beyond which the ML performs better for all estimates seems to be 150, which is lower than suggested by Olson *et al.*

Table 4.3-1 Comparative Performance of the ML and COLS Estimator [1]

Sample	β_0		β_1		β_2		σ^2	
Size	COLS	ML	COLS	ML	COLS	ML	COLS	ML
				Bias [2]				
30	-0.265	-0.978	0.033	-0.012	0.058	-0.029	0.950	-2.755
50	-0.245	-1.464	0.009	0.013	0.046	0.018	0.684	-2.580
100	-0.108	-0.988	0.040	-0.018	-0.003	-0.024	0.402	2.621
150	0.192	0.354	0.035	0.012	0.013	0.022	0.411	1.398
200	0.180	0.161	-0.002	0.003	-0.016	0.017	0.363	-0.834
				Variance [2]				
30	19.04	20.25	0.275	0.235	0.286	0.221	13.59	2.207
50	10.21	8.646	0.138	0.113	0.140	0.109	6.929	2.681
100	5.958	5.318	0.081	0.063	0.060	0.061	4.151	2.534
150	4.931	4.812	0.067	0.058	0.053	0.049	3.754	2.087
200	3.048	2.934	0.029	0.014	0.034	0.028	2.858	1.930
				Mean Square Error [2]				
30	19.11	21.20	0.276	0.236	0.290	0.222	14.50	9.797
50	10.27	10.79	0.138	0.113	0.142	0.110	7.397	9.337
100	5.970	6.294	0.082	0.063	0.060	0.062	4.312	9.404
150	4.968	4.937	0.068	0.058	0.053	0.049	3.923	4.041
200	3.080	2.956	0.029	0.014	0.034	0.028	2.990	2.626

Notes:

[1] Replications=200.

[2] Bias, variance and mean square error are the Monte Carlo moments of parameter estimates.

The finite sample distributions of both the COLS and the ML estimators are unknown. Since we can derive the asymptotic distribution of the estimators of the second and the third moments of the COLS residuals using the central limit theorem, and COLS estimates of the parameters of the model are differentiable functions of these estimated moments, the asymptotic distribution of the COLS estimator is tractable. But the expressions are messy (Olson, *et al.*, 1980). Large sample tests based on the ML method are applicable in frontier models. For instance, 'asymptotic t ratios' (the ratio of the coefficient estimate to the square root of the appropriate diagonal element of the inverse of the information matrix) are asymptotically distributed as N(0,1) under the null hypothesis that the associated coefficient is zero (Aigner *et al.*, 1977). An asymptotic chi–square static can also be used for significance test, since the negative of twice the logarithm of the generalised–likelihood ratio for a number of problems (e.g. the significance of the one–sided term U_i or the restrictions on parameters) has approximately chi–square distribution (Battese and Coelli, 1988).

According to Jondrow *et al.* (1982) we can use either the mean or the mode of the distribution of U_i conditional on Z_i as an estimate of U_i for each observation. Given normal V_i and half–normal U_i, V_i and U_i are independent, and $Z_i = V_i - U_i$, the mean of the distribution of U_i conditional on Z_i is

$$(4.3\text{-}11) \qquad E(U_i/Z_i) = \mu^* + \sigma^* \frac{\varphi(-\mu^*/\sigma^*)}{1-\Phi(-\mu^*/\sigma^*)}$$

where $\mu^* = -\sigma_u \epsilon/\sigma$

$\sigma^* = \sigma_u \sigma_v/\sigma.$

For the exponential model, this is

$$(4.3\text{-}12) \qquad E(U_i/Z_i) = \zeta_i + \sigma_v \varphi(z_i/\sigma_v)/\Phi(z_i/\sigma_v)$$

where $\zeta_i = Z_i - \theta\sigma_v^2.$

4.4 Parametric Estimates of Productive Efficiency: "Cross-sectional Analysis"

The empirical exercise involves fitting the two-factor stochastic frontier model Eq(4.3-5), using both the ML and OLS (=COLS except for the constant term), to a cross-section of British port data. The annual samples of British ports during the period 1983-1990 contain no more than 37 observations. A problem, which frequently arises in frontier estimation when the sample is not large enough, is the occurrence of wrong (negative) skewness of OLS residuals. In a stochastic frontier model, if there is no inefficiency, the true disturbance will be symmetric. In the presence of inefficiency the disturbance should be positively skewed. As such, the skewness of sample residuals is informative about the extent of inefficiency (Greene, 1991, 1, pp.328-329). Actually our 1989 and 1990 samples do involve wrong skewness of OLS residuals. The negative skewness of OLS residuals casts doubt on the existence of inefficiency. However, there can be other causes for the wrong skewness: either because the model is not well specified, or simply due to sample variation. It has been confirmed in our Monte Carlo analysis that the occurrence of wrong skewness becomes higher as sample size gets smaller even though the true disturbance is asymmetric. Thus a proper strategy to deal with wrong skewness is to enlarge the sample size before jumping to the conclusion that there is no inefficiency or that model specification is inappropriate.

For this reason we enlarged the sample of British ports by pooling cross-sectional and time-series data and treated the pooled data as if they were generated from the cross-sectional units in one period. The panel of observations used here consists of 28 major and medium British ports during 1983-1990. In total there are 189 observations. It is unbalanced because of missing and incomplete data. Since no information on input and output prices is provided in annual reports of British ports, the best thing that can be done is to deflate the time series data by using general price indices. Output is defined as turnover in constant GDP market prices of 1985. Labour input is defined as staff costs in constant GDP factor cost of 1985. Capital input is defined as net-book value of fixed capital assets at 1985 prices. The implied deflator for capital is derived from capital consumption at current prices and at 1985 prices for the transport sector.

This was a procedure adopted by Greene (1991, 2) who applied a cross-sectional frontier model to an unbalanced panel of observations on output and inputs for 10 American airlines from 1970 to 1984. Strictly speaking, the procedure is justified only if the state of technology remains unchanged over the time period under investigation. Otherwise efficiency comparison between firms will be biased against firms observed in the earlier years because the most productive technology currently available was not available earlier. Practically the problem is negligible as long as the technology does not change rapidly and/or the span of the time period is relatively short. In the port industry, while the "container revolution" of the 1960s and 1970s rapidly changed cargo handling out of all recognition, the speed of the cargo handling techonology development slowed down in 1980s. It is then reasonable to fit one best-practice technology to measure inter-port efficiency for the whole period. In the next chapter we will consider if there is any sample evidence to suggest structural changes in the best-practice technology. A further justification for this procedure is that every port in the sample has observations for the early years as well as for later years. Thus every port has a more or less equal chance of being "fairly" or "unfairly" treated even if there are significant shifts in the production frontier due to rapid technical progress.

Furthermore frontier functions are closely related to long-run or *ex-ante* production functions, since firms can, in the long run, choose the best technology (Heathfield and Wibe, 1987). We cannot expect firms to move to the best-practice technology at any cost in the short run. Thus it can be argued that comparison of productive performance is more meaningful over a longer period of time provided that the best-practice technology remains fixed.

Using the pooled data instead of the annual data also helps us in getting more precise estimates. There was a severe problem of multicollinearity, probably because of larger number of variables in the translog function, when the annual data set is used. As we will see shortly that the problem disappears when the pooled data is used.

As mentioned in section 4.1, existing frontier models can be modified to allow the use of panel data. One can specify either a fixed-effect or a random-effect frontier model with a firm effect but no time effect in the usual framework of panel data literature. Actually some serious difficulties with the cross-section models are potentially avoidable in the panel-data models. Nevertheless, the techniques of panel-data analysis are focused on cross-sectional variation assuming there is no variation over time. This is equivalent to assuming that the efficiency of the individual firms is invariant with time. It is this questionable assumption that makes the panel data models unattractive to us. In the next chapter, a framework will be set up to investigate the time-series variation of port efficiency.

Numerous solution algorithms are available for finding the ML estimates. But based on our experience in the Monte Carlo analysis, the likelihood function seems ill-behaved and the function either converges slowly or does not converge if the algorithm and the step size are not properly chosen. This is so when using the Newton procedure, for instance, even if the initial value and step size are very carefully chosen. The occurrence of algorithm failure is high especially when a sample is small and the variance ratio ($\lambda=\sigma_u/\sigma_v$) is high. The iterations were performed by the Fletcher-David-Powell procedure that we programmed using *Gauss* (Version 2.0 [1]). The procedure, which belongs to the class of quasi-Newton methods, was very powerful as compared with the Newton procedure in our Monte Carlo experiments. The initial values of parameters were given by the consistent COLS estimates. Econometric packages for frontier estimation are readily available now, for instance, in *Limdep* (Version 6.0 [2]).

Notes:

[1] For the manual of Gauss (Version 2.0) see Edlefsen and Jones (1984).

[2] For the manual of Limdep (Version 6.0) see Greene (1990,2).

The estimation procedure begins with checking the skewness of the OLS residuals, since if they are not significantly positively skewed there is no point in proceeding. The histogram of the OLS residuals plotted has a longer tail on the negative direction. This means that the OLS residuals derived from our model is well-shaped. Waldman (1982) has suggested checking the sign of the third moment

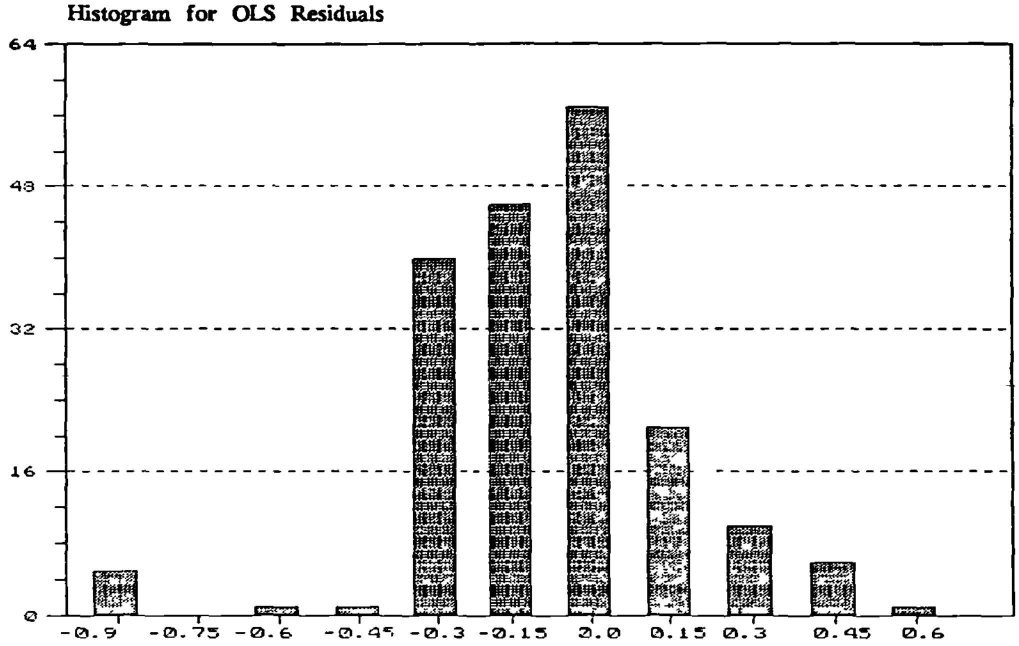


Fig 4.3-1 Skewness of the OLS Residuals

of the OLS residuals. The true compound disturbance term has a negative mean (=-E(U)) and is positively skewed in the presence of inefficiency. Since the sample of OLS residuals converges to the sample of true disturbances, the OLS residuals are wrongly (negatively) skewed if the third moment is positive. Whenever this happens the maximum likelihood estimator for the stochastic production frontier model is simply the OLS estimator and the implied σ_u is zero. Greene (1991, 1), pp.328-330) has provided a procedure to test normality of the true disturbances, when the third moment of the OLS residuals is indeed positive, by computing the skewness and excess coefficients. The third moment of the OLS residuals for our frontier model is –0.607, impling that the OLS residuals are correctly (positively) skewed. This is confirmed by the histogram of OLS residuals plotted in Fig 4.3–1, which has a longer tail on the negative direction. Thus at this point sample evidence is neither against the specification of our model – either the deterministic (here translog) or stochastic part, nor the existence of inefficiency.

Various sets of parameter estimates of the stochastic translog frontier production function Eq(4.3–5) are presented in Table 4.4–1. The first column of entries corresponds to the result running the OLS. The second two columns of entries are the results of the ML estimation under half–normal and exponential assumptions.

Since the sample size is larger than 150, the ML is expected to perform better according to our experience of the Monte Carlo analysis. It can be seen that asymptotic variances of the ML estimates tend to be smaller than the variances of the OLS estimates. The comparison between the ML and the OLS estimates sheds light on the difference between the frontier technology and the average technology in the industry. As expected, on the frontier the intercept term, indicating the level of purely productive efficiency, is greater than in the OLS 'average' function. The frontier technology is characterised with the higher output elasticity for labour and lower output elasticity for capital.

To test the appropriateness of the functional form, two alternative deterministic specifications are considered: Cobb–Douglas and CES. The corresponding estimates of the Cobb–Douglas model are given in Table 4.4–2. The Cobb–Douglas model assumes unitary elasticity of substitution, constant elasticity of scale (estimated to be 0.867), and strongly disposability for the best–practice technology. A Cobb–Douglas function may be written

$$(4.4\text{-}1)\quad \ln Y_i = \ln\gamma_0 + \alpha_1 \ln X_{1i} + \alpha_2 \ln X_{2i}$$

which is a restricted version of the translog function Eq(4.3–1). The relevant restrictions are $\beta_1=\beta_2=\gamma_1=0$. A test of the adequacy of the Cobb–Douglas model is obtained from the generalised likelihood ratio. The negative of twice the logarithm of the likelihood ratio has approximately a chi–distribution with degree of freedom equal to 3. Given the maximised values of the logarithm of the likelihood function in the exponential and the half–normal cases for both the translog and the Cobb–Douglas models, the values of this statistic are 45.0 in the half–normal case and 51.0 in the exponential case. These values are significant even at the 0.5% level. We thus conclude that the Cobb–Douglas is not a suitable specification for the efficiency frontier of the British port industry.

The CES function having the property of homogeneity and constant elasticity of substitution, which can be written

$$(4.4\text{-}2)\qquad \ln Y_i = \ln\gamma_0 - \frac{\upsilon}{\rho}\ln[(1-\delta)X1_i^{-\rho} + \delta X1_i^{-\rho}]$$

A Taylor series approximation to this function around the point $\rho=0$ is

$$(4.4\text{-}3)\qquad \ln Y_i = \ln\gamma_0 + \upsilon(1-\delta)\ln X1_i + \upsilon\delta\ln X2_i - (1/2)\rho\upsilon\delta[\ln X1_i - \ln X2_i]^2$$

or

$$(4.4\text{-}4)\qquad \ln Y_i = \ln\gamma_0 + \alpha_1\ln X1_i + \alpha_2\ln X2_i + \beta_1[\ln X1_i - \ln X2_i]^2$$

where $\alpha_1=\upsilon(1-\delta)$, $\alpha_2=\upsilon\delta$, $\beta_1=-(1/2)\rho\upsilon\delta$.

It is easy to see that Eq(4.4–4) can be obtained by imposing restrictions on the translog model $\beta_1=\beta_2=-2\gamma_1$. The estimates of the CES model are presented in Table 4.4–3. The negative of twice the logarithm of the likelihood ratio has approximately a chi–distribution with degree of freedom equal to 2. The value of general likelihood ratio is 3.44 for the half–normal case and 0.98 for the exponential case. The critical value from the chi–square table is 5.99 at the 5% level, so we would not reject that the CES model is appropriate.

Table 4.4–1 The Translog Production Frontier of the British Port Industry: "Cross-sectional" Analysis

Estimator	OLS	ML	
Error Specification		Half-Normal	Exponential
R^2	0.956	–	–
$\bar{R}^2$	0.955	–	–
Residual-squared	12.553	–	–
Log-likelihood	-12.349	-8.064	-1.758
Constant	-2.229	0.193	0.620
	(1.102)	(1.114)	(1.009)
$\log X_{1i}$	0.696	0.608	0.687
	(0.267)	(0.204)	(0.181)
$\log X_{2i}$	0.949	0.562	0.370
	(0.265)	(0.264)	(0.257)
$(\log X_{1i})^2$	0.113	0.089	0.077
	(0.028)	(0.021)	(0.019)
$(\log X_{2i})^2$	0.046	0.048	0.056
	(0.021)	(0.025)	(0.021)
$\log X_{1i} \log X_{2i}$	-0.195	-0.148	-0.139
	(0.048)	(0.043)	(0.036)
$\lambda = \sigma_u / \sigma_v$		1.851	-
		(0.563)	-
σ		0.361	-
		(0.028)	-
θ		-	5.531
		-	(0.735)
σ_v		-	0.176
		-	(0.018)

Note: Standard errors of the estimators are given in parentheses below the parameter estimates.

Table 4.4–2 The Cobb–Douglas Production Frontier of the British Port Industry: "Cross-sectional" Analysis

Estimator	OLS	ML	
Error Specification		Half-Normal	Exponential
R^2	0.943	–	–
$\bar{R}^2$	0.942	–	–
Residual-squared	16.205	–	–
Log-likelihood	-36.350	-30.575	-27.246
Constant	1.699	2.024	1.850
	(0.128)	(0.117)	(0.115)
$\log X_{1i}$	0.638	0.632	0.636
	(0.167)	(0.015)	(0.014)
$\log X_{2i}$	0.229	0.230	0.235
	(0.021)	(0.014)	(0.012)
$\lambda=\sigma_u/\sigma_v$		1.920	-
		(0.470)	-
σ		0.410	-
		(0.028)	-
θ		-	4.979
		-	(0.736)
σ_v		-	0.206
		-	(0.019)

Note: Standard errors of the estimators are given in parentheses below the parameter estimates.

Table 4.4-3 The CES Production Frontier of the British Port Industry "Cross-sectional" Analysis

Estimator	OLS	ML	
Error Specification		Half-Normal	Exponential
R^2	0.952	-	-
$\bar{R}^2$	0.951	-	-
Residual-squared	13.652	-	-
Log-likelihood	-20.24	-9.777	-2.245
Constant	1.249	1.461	1.227
	(0.166)	(0.151)	(0.137)
$\log X_{1i}$	0.778	0.755	0.770
	(0.031)	(0.082)	(0.066)
$\log X_{2i}$	0.138	0.164	0.167
	(0.027)	(0.084)	(0.068)
$\log(X_{2i}/X_{1i})$	0.060	0.057	0.061
	(0.010)	(0.020)	(0.017)
$\lambda=\sigma_u/\sigma_v$		2.259	-
		(0.568)	-
σ		0.384	-
		(0.024)	-
θ		-	5.263
		-	(0.603)
σ^{V}		-	0.170
		-	(0.017)

Note: Standard errors of the estimators are given in parentheses below the parameter estimates.

The existence of inefficiency can also be tested on the significance of the one-sided term U in the frontier model Eq(4.3-5). If the error term is absent from the model (i.e., $E(U_i)=0$), then the OLS estimator is identical to the ML estimator. The negative of twice the logarithm of likelihood ratio is approximately chi-distributed with 1 degree of freedom. The value of this statistic is 8.6 in the half-normal case and 21.8 in the exponential case, both of which are significant even at the 0.5% level.

The mean of the inefficiency component U according to Eq(4.3-7) is

$$E(U_i) - 0.254$$

under the half-normal assumption, implying that the average shortfall of output is 25% below the stochastic frontier. This is equivalent to 78% (=EXP(-U)) efficiency. Under the exponential assumption, the mean of the inefficiency component U_i according to Eq(4.3-8) is

$$E(U_i) - 0.181$$

implying an 18% average shortfall of output below the stochastic frontier or 84% efficiency. The difference between the two estimates is 7%.

The relative importance of inefficiency in relation to exogenous influences can be indicated by the relative variability of the two sources of random error that distinguish ports from one another. In the half-normal case, given the estimated values of λ $(=\sigma_u/\sigma_v)$ and $\sigma(\sigma^2=\sigma_u^2+\sigma_v^2)$, the implied estimates of $\sigma_u^2=0.101$ and of $\sigma_v^2=0.029$. The variance of U, according to Eq(4.3-7), is calculated as

$$Var(U_i)-0.036$$

which is 55% of the total disturbance (N.B. $Var(Z)=Var(U)+Var(V)=Var(U)+\sigma_v^2$). It is important to note that the variance of U is not σ_u^2 while the variance of V is σ_v^2). In the exponential case, given estimated θ and σ_V, the variance of U according to Eq(4.3-8) is calculated as

$$\mathrm{Var}(U_i)=0.033$$

which is 52% of the total disturbance. Again both measures are close. Therefore, the picture that emerges is one of substantial variations of observed output beneath the frontier as much as variations in the frontier across ports.

Estimated pure productive inefficiencies, for 28 British ports from 1983 to 1990 relative to the best-practice technology available during this period, are computed using Jondrow's procedure and are given in Table A4.4-1 of Appendix 4.4. Shown in Fig.4.4-2 and Fig 4.4-3 are the histograms of time averages of estimated efficiencies for each port for the half-normal and exponential cases respectively. It appears that the distribution of estimated efficiencies under the exponential assumption is half-normally shaped while the distribution of estimated efficiencies under the half-normal assumption is not. Farrell (1957) believd that a plausible shape of genuine efficiency distribution is such as the half-normal, with mode at maximum efficiency while any other shapes, such as rectangular, unimodal, the shape with mode at minimum efficiency, are implausible. If Farrell's criterion is accepted here, we should feel that the assumption of exponential distribution and hence the corresponding efficiency estimates are more plausible.

The translog specification does not exclude the possibility of congestion and allows variability of scale elasticity in the technology. Thus the efficiency frontier itself can be congestive and scale inefficient. To detect congestion inefficiency, the marginal productivity of labour and capital on the translog frontier are calculated for each observation. The results, shown in Table A4.4-2 of Appendix 4.4, suggest a positive marginal product of capital and labour for all sample ports except Harwich Dock during 1983-1990. This implies that the weakly disposable frontier

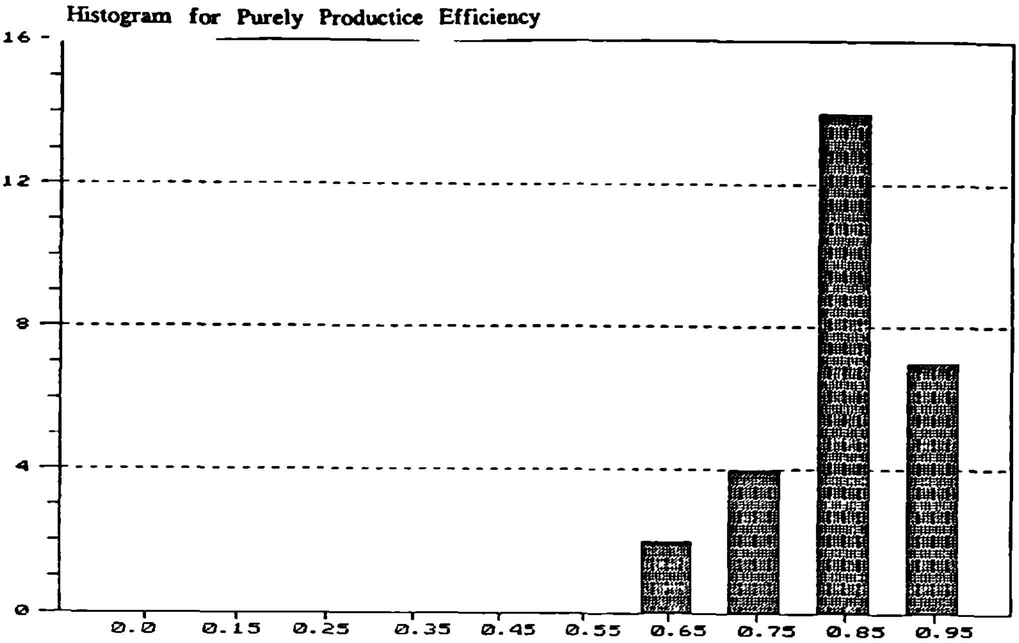


Fig 4.4–2 Distribution of Pure Productive Efficiency of British Ports 1983–90

(Half–Normal Assumption)

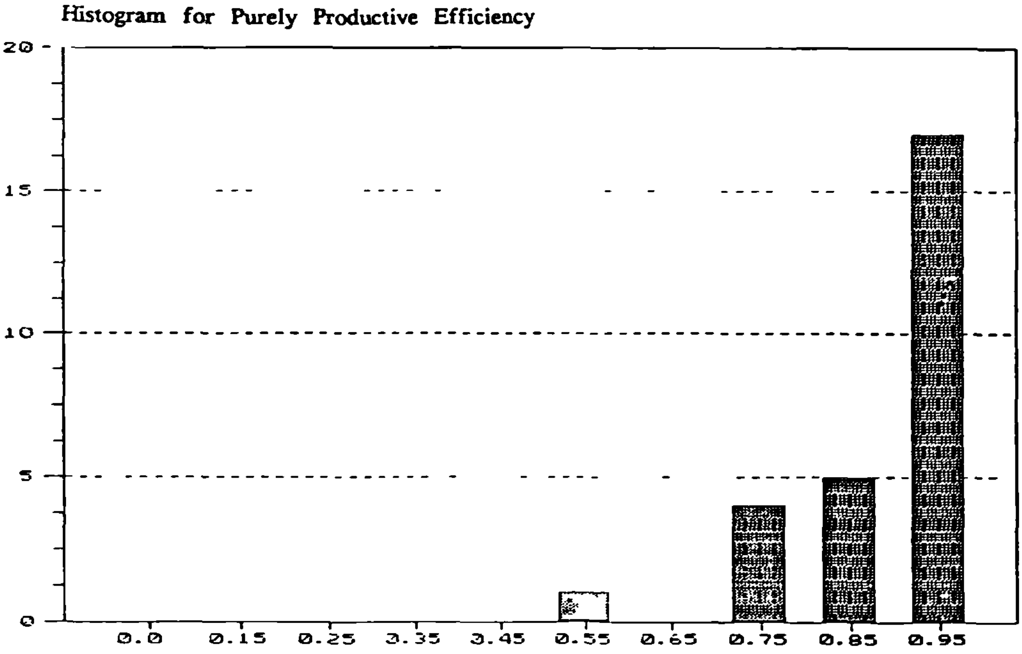


Fig 4.4–3 Distribution of Pure Productive Efficiency for British Ports 1983–90

(Exponential Assumption)

coincides with the strongly disposable frontier. Therefore most sample ports during this period are congestively efficient.

The values for the elasticity of scale on the translog frontier for all observations are also evaluated and given in Appendix 4.4-3. The values are less than one for most observations, indicating the existence of scale inefficiency and that was due to operation at non-optimal scale when decreasing returns to scale prevailed. Following the procedure outlined in the previous section, scale inefficiencies are calculated for 28 British ports during 1983-1990. The results are shown in Tables A4.4-3 (derived from the weakly disposable technology associated with the half-normal assumption) and A4.4-4 (derived from the weakly disposable technology associated with the exponential assumption) of Appendix 4.4. The distribution of estimated scale efficiencies plotted in Fig 4.4-4 is far from half-normally shaped. However, Farrell's criterion is not relevant to scale efficiency. As indicated earlier, while purely productive and congestive inefficiency are private inefficiency, scale inefficiency arising from the departure of the long run competitive equilibrium need not imply managerial inefficiency, though it is undesirable in a social sense. It is hardly surprising that the distribution of scale efficiency could be irregular.

As a final note, the estimated values of efficiency is meaningfully related to the values of scale elasticity. As can be seen in Fig 4.4-5 the values of scale efficiency are higher when the values of scale elasticity are closer to unity, meaning that scale inefficiency can be eliminated by moving actual scale size towards the most productive scale size.

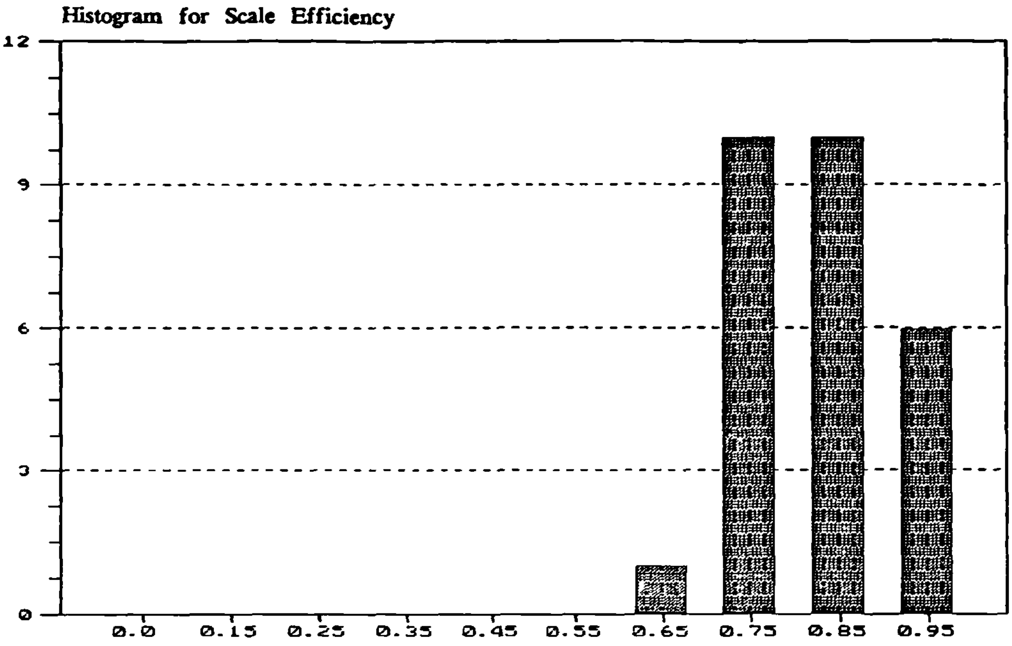


Fig 4.4-4 Distribution of Scale Efficiency of British Ports 1983-1990

(Exponential Assumption)

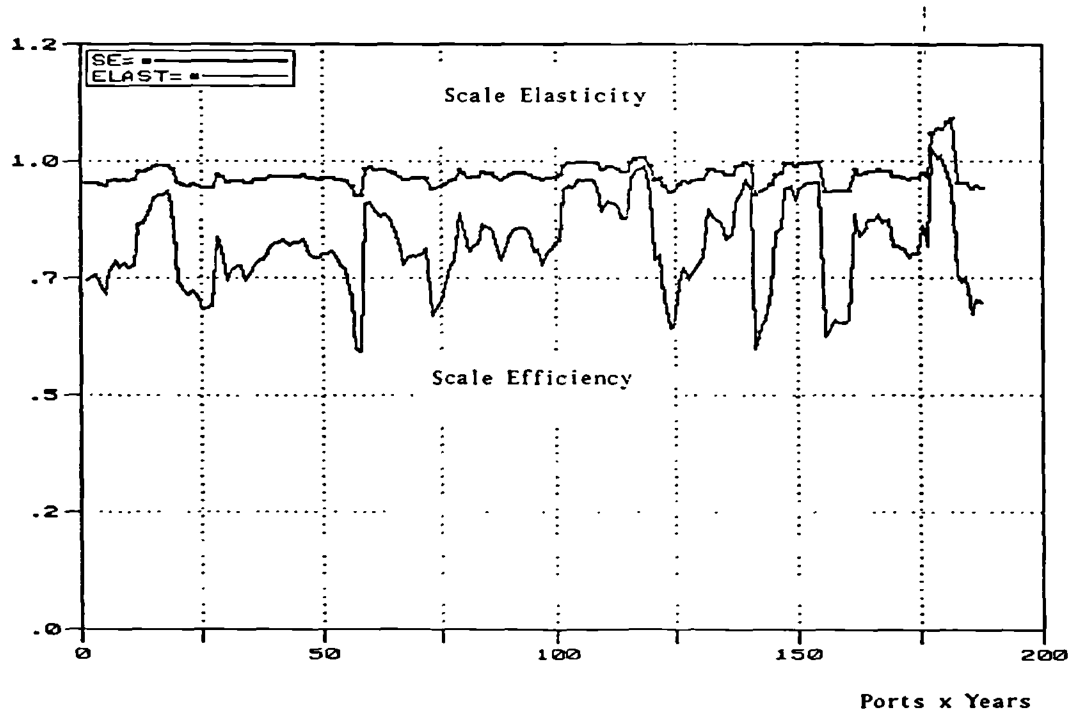


Fig 4.4-5 Scale Efficiency and Scale Elasticity

4.5 Parametric Estimates of Productive Efficiency: Panel Data Analysis

In the last section we applied the cross-sectional frontier model to the pooled data. As stated in Section 4.1 the cross-sectional analysis hinges on assumptions about non-independence of regressors and productive inefficiency and about the the distribution of inefficiency. However, if a port knows its efficiency level, this will affect its choice of inputs. In consequence the regressors are likely to be correlated with inefficiency. The same effect may arise if some relevant factor of production is omitted. For instance, some ports may appear as more efficient than others because of the non-measurement of location in our models. It might be reasonable to expect that ports with a favourable location may tend to be larger because of the higher marginal productivity of capital and labour. The distributional assumptions (half-normal or exponential) can also be questioned since they are arbitrary. Both of these two assumptions are potentially avoidable if one has panel data. In this section we consider whether better estimates can be obtained from the extra information provided by panel data.

The estimators to be used are the Within, the GLS and the ML, which have been briefly described in Section 4.1. Note that the ML estimator here is the one developed by Pitt and Lee (1981) for panel data rather the one used in the last section for "cross-sectional data". The appropriateness of these estimators depends on the validity of the assumptions about the independence of the regressors and inefficiency and about the distribution of inefficiency. These assumptions can in turn be tested using Hausman-type tests. Since the GLS estimator assumes that the effects (U_i) are uncorrelated with the regressors while the Within estimator does not, the null hypothesis that effects and regressors are uncorrelated can be tested by testing the significance of difference between these two estimators. In using the ML estimator the effects are assumed independent of regressors, and specific distributional assumptions are assigned for U_i and V_{it}. Given that the effects are uncorrelated with the regressors, a Hausman test on the difference between the GLS and ML is equivalent to a test of the distributional assumption. Finally the joint hypothesis that the effects are uncorrelated with the regressors and that the distributional assumptions are correct can be tested by a Hausman test of the difference between the Within and ML.

Table 4.5-1 displays the Within, GLS, and ML estimates of the frontier production function. We assume a translog technology and Hicks-neutral technological change. The ML estimates are obtained under the exponential distribution. The DFP algorithm is unable to locate a maximum for the likelihood function under the half-normal distribution. The estimated rate of technical progress is between 1.3% and 1.6% per year. All three sets of results are close in terms of the coefficients, $\bar{R}^2$, σ_v^2, and significance of the coefficients.

Table 4.5-1 The Translog Production Frontier of the British Port Industry: Panel Data Analysis

Estimator	Within	GLS	ML
$\bar{R}^2$	0.996	0.950	0.950
σ_u^2	-	0.110	0.259
σ_v^2	0.006	0.006	0.006
Time	0.013	0.014	0.016
	(0.003)	(0.003)	(0.004)
Constant	-	-0.976	0.897
		(1.366)	(2.296)
$\log X_{1it}$	0.739	0.670	0.367
	(0.211)	(0.191)	(0.273)
$\log X_{2it}$	0.760	0.791	0.726
	(0.220)	(0.190)	(0.374)
$(\log X_{1it})^2$	0.047	0.058	0.070
	(0.014)	(0.013)	(0.022)
$(\log X_{2it})^2$	0.009	0.009	0.010
	(0.010)	(0.009)	(0.014)
$\log X_{1it} \log X_{2it}$	-0.094	-0.107	-0.090
	(0.022)	(0.021)	(0.029)

Note: Standard errors of the estimators are given in parentheses below the parameter estimates.

The Hausman test statistic is asymptotically distributed as a chi-distribution with 6 degrees of freedom. The value of the statistic is 5.828 for the difference between the Within and the GLS. This means that the null hypothesis of no correlation between effects and regressors is accepted. Given the uncorrelatedness of the effects and regressors, the distributional assumption is tested by comparing the GLS and ML. The value for the relevant Hausman test statistic is 0.522. So we would not reject the exponential distribution. The test of the joint hypothesis of uncorrelated regressors and correct distributional assumption is based on the difference between the Within and the ML. For this test, the value of the statistic is 1.267. Again this is well Within the acceptance region at the 5% level.

Given that there is no sample evidence against the ML estimator for panel data, we are now in a position to compare the ML estimates from the panel data with the ML estimates from the pooled data. The efficiency estimates derived from both estimators are displayed in Table A4.5-1 in Appendix 4.5 to this chapter. While the estimates from the panel data are constant for each port over time, the corresponding estimates from the pooled data are time averages. There is no direct test between these two estimators, but we may use Farrell's (1957) "goodness of fit" measure to compare the plausibility of efficiency estimates. The efficiency error distribution derived from the Pitt and Lee ML estimator is plotted in Fig 4.5-1. Recall that, on Farrell's criterion, the distribution of efficiency estimates derived from the cross-sectional model is plausible under the exponential assumption (see Fig 4.4-3). The distribution of efficiency estimates derived from the Pitt and Lee ML estimator plotted in Fig 4.5-1, however, is implausible.

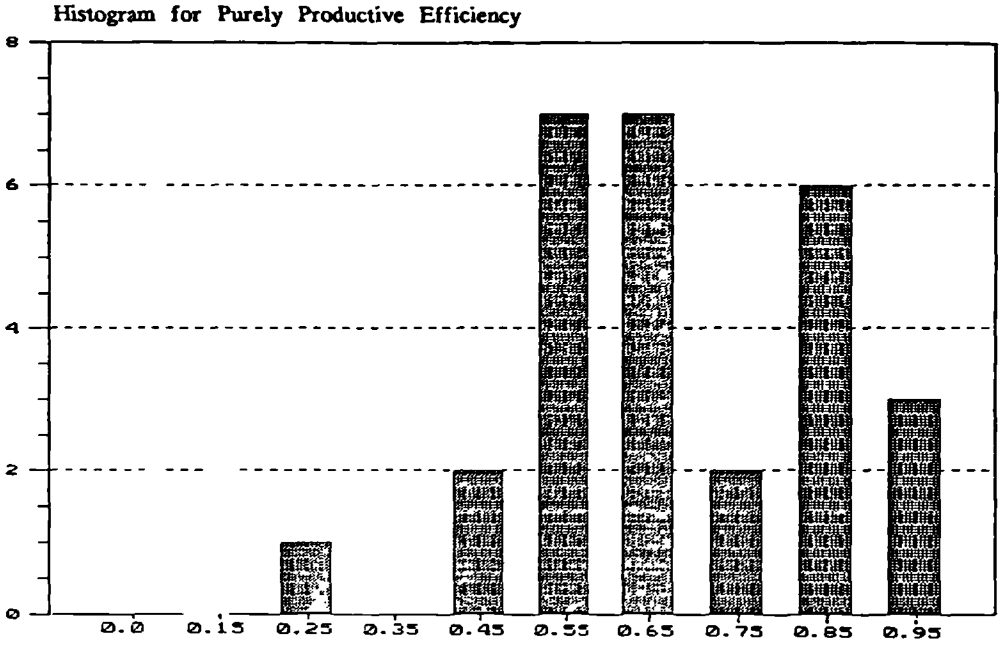


Fig4.5-1 Distribution of Purely Productive Efficiency of British Ports 1983-1990

(Panel Data Model/Exponential Assumption)

4.6 Stochastic versus Deterministic Frontier

It is hardly surprising that efficiency estimates relative to a stochastic production frontier are different from efficiency estimates relative to a deterministic frontier. In this study the deterministic frontier is assumed to be piece-wise linear, while the stochastic frontier is assumed to be translog for the technology, and half-normal or exponential for inefficiency. Which measure is closer to the true extent of efficiency? Recall that the deterministic approach imposes no structure but cannot deal with statistical noise, whereas the stochastic approach can handle statistical noise but imposes structure. The answer to this question should then depend on whether the data was contaminated by statistical noise, and whether the structure was well-specified for the stochastic frontier. The results from estimating the stochastic frontier model suggest substantial statistical noise, because the estimated variance of the symmetric error component is as high as the estimated variance of the asymmetric error component. In other words we have empirical evidence for believing that the data set has been contaminated by statistical noise. Certainly this is based on the structure we pre-specified so that we are not absolutely sure whether this is true unless we are convinced that the structure has been correctly specified. However, in the following two aspects the study described in this chapter represents an advance as compared with previous work on stochastic frontier models. First, we have specified and estimated a less restrictive model for the production technology. Secondly, specifications for the production technology and error structure have been subject to statistical tests. These enable us to base our efficiency estimates on a well-specified structure consistent with the sample evidence. Therefore we have some reasons for preferring the stochastic measures.

Table 4.6-1 shows estimates of average productive efficiency of British ports relative to deterministic and stochastic frontiers based on exactly the same sample (observations of 28 British ports during the period 1983-1990). For the purpose of comparison between stochastic and deterministic measures, the sample chosen here for non-parametric estimation is the pooled data set used in this chapter instead of the annual data sets used in Chapter 3. Since efficiency measures derived from production functions are output-based, the efficiency measures relative to the deterministic frontier presented in the same table are output-based as well. For deterministic measures structural efficiency was taken as the average value. To compute structural efficiency (see van den Broeck, *et al.*, 1980), we construct an average port (arithmetic average of each amount of inputs and output) for the industry, and regard this average port as an arbitrary observation on the same line as the other observations, and then compute efficiency for this average port. For parametric measures EXP(−E(U)) was taken as the average value for purely productive efficiency (PTE) and the arithmetic mean is taken as the average value for scale efficiency (SE) and congestive efficiency (CE). The average of non-price overall productive efficiency (OTE) is the product of average values of PTE, SE and CE.

Table 4.6–1 Deterministic and Stochastic Measures of Average Productive Efficiency of British Ports

Measures	OTE	PTE	SE	CE
Relative to a stochastic frontier				
half-normal	63.6%	77.6%	81.9%	100%
exponential	66.3%	83.4%	79.5%	100%
Relative to a deterministic frontier				
	39.2%	70.5%	56.7%	98.1%

Notes:
All measures are output-based;
Stochastic measures of PTE are the means of U_i;
Stochastic measures of SE are the sample means of SE;
Deterministic measures are values of structural efficiency.

Several points in the table are worthy of comment. First, the deterministic measures are lower than the stochastic measures of efficiency probably because the former over–estimate the true extent of inefficiency. Second, while both measures differ largely in terms of SE, they are relatively close in terms of PTE and very close in terms of CE. Therefore the results obtained from the stochastic and the deterministic model are in agreement that the most important ways in which British port producers depart from overall non–price productive efficiency are purely productive and scale inefficiency, while congestive inefficiency is negligible.

Appendix 4.4
Parametric Efficiency Estimates

Table A4.4-1
Parametric Estimates of Purely Productive Inefficiency

Ports	Years	Purely Productive Inefficiency	
		Half-Normal	Exponential
ABP			
	1	0.158488	0.112576
	2	0.242491	0.172336
	5	0.098600	0.072303
	6	0.082702	0.063579
	7	0.062430	0.051277
Bristol			
	3	0.423384	0.347037
	4	0.345564	0.256288
	5	0.361331	0.276000
	6	0.349330	0.260463
	7	0.388054	0.304398
	8	0.367197	0.279895
Clyde			
	1	0.260444	0.165642
	2	0.252833	0.160260
	3	0.248500	0.154694
	4	0.237925	0.143723
	5	0.227030	0.136235
	6	0.240896	0.145696
	7	0.225717	0.135643
	8	0.146627	0.092238
Dover			
	1	0.149820	0.106109
	2	0.158695	0.114149
	3	0.160068	0.116754
	4	0.131578	0.095995
	5	0.152205	0.112166
	6	0.189387	0.143487
	7	0.110438	0.084669
	8	0.101946	0.078486
Felixstowe			
	1	0.209644	0.132974
	2	0.221887	0.145115
	3	0.279664	0.208277
	4	0.256327	0.181843
	5	0.176924	0.121298
	6	0.155843	0.107155
	7	0.182448	0.130223
	8	0.192618	0.135173
Forth			
	1	0.186406	0.126716
	2	0.142833	0.097493
	3	0.130415	0.089897
	4	0.133026	0.089246
	5	0.178051	0.116142
	6	0.144723	0.095408
	7	0.107891	0.073824

Table A4.4-1 (Continued)
Parametric Estimates for Purely Productive Inefficiency

Ports	Years	Purely Productive Inefficiency	
		Half-normal	Exponential
London			
	1	0.190315	0.121322
	2	0.203702	0.128946
	3	0.209024	0.132201
	4	0.157436	0.099960
	5	0.133331	0.089644
	6	0.132470	0.089988
	7	0.149865	0.100907
	8	0.131959	0.089126
Manchester			
	1	0.332562	0.238803
	2	0.346537	0.250417
	3	0.415296	0.326524
	4	0.288669	0.205988
	5	0.280993	0.200756
	6	0.360128	0.296906
	7	0.505329	0.509785
	8	0.416402	0.392460
Medway			
	1	0.237693	0.143622
	2	0.182700	0.109605
	3	0.188166	0.114476
	4	0.246483	0.153172
	5	0.233324	0.143151
	6	0.215692	0.133007
	7	0.209374	0.131722
	8	0.172159	0.113066
Mersey			
	3	0.248706	0.172437
	4	0.233924	0.158137
	5	0.226375	0.150908
	6	0.201602	0.134257
	7	0.228465	0.151899
	8	0.172964	0.113451
Milford Haven			
	1	0.350189	0.247085
	2	0.313943	0.212588
	3	0.209944	0.133792
	4	0.191539	0.121121
	5	0.196294	0.124538
	6	0.161840	0.102842
	7	0.148902	0.094648
	8	0.232478	0.147641
Tees & Hartlepool			
	1	0.153787	0.102660
	2	0.165900	0.108682
	3	0.147030	0.096946
	4	0.131942	0.084617
	5	0.157911	0.099412
	6	0.170500	0.107625
	7	0.126789	0.084863
	8	0.114486	0.080228

Table A4.4-1 4.4-1 (Continued)
Parametric Estimates for Purely Productive Inefficiency

Ports	Years	Purely Productive Inefficiency	
		Half-normal	Exponential
Tyne			
	3	0.285271	0.194546
	4	0.187531	0.119964
	5	0.170215	0.108699
	6	0.168150	0.107153
	7	0.166610	0.106210
	8	0.170836	0.109855
Aberdeen			
	1	0.089828	0.063404
	2	0.088731	0.062682
	3	0.098721	0.069210
	4	0.109800	0.074923
	5	0.105851	0.072476
	6	0.104377	0.071314
	7	0.102876	0.070417
Ardrossan			
	1	0.487969	0.383840
	2	0.440100	0.329230
	3	0.453531	0.343790
	4	0.455688	0.347292
	5	0.447500	0.338549
	6	0.479749	0.375933
	7	0.448451	0.339865
	8	0.391359	0.278281
Blyth			
	3	0.140345	0.089680
	4	0.167435	0.103930
	5	0.332785	0.219889
	6	0.403014	0.287387
	7	0.351085	0.240681
	8	0.256377	0.163114
Boston			
	3	0.234125	0.146072
	4	0.195675	0.121090
	5	0.346285	0.230905
	6	0.243304	0.151568
	8	0.226944	0.141459
BWB			
	3	0.513647	0.558632
	4	0.484032	0.514115
	5	0.557016	0.560840
	6	0.522740	0.620020
	7	0.547008	0.678660
Cromarty Firth			
	3	0.375859	0.240633
	4	0.391662	0.258334
	5	0.612019	0.508867
	6	0.357517	0.227625
	7	0.398107	0.267965
	8	0.419826	0.290395
Dundee Firth			
	1	0.219556	0.136929
	2	0.185143	0.115539

Table A4.4-1 (Continued)
Parametric Estimates for Purely Productive Inefficiency

Ports	Years	Purely Productive Inefficiency	
		Half-normal	Exponential
Dundee Firth			
	5	0.155650	0.098346
	6	0.167724	0.105289
	7	0.167506	0.106101
	8	0.189934	0.119933
Great Yarmouth			
	3	0.069168	0.049993
	4	0.061994	0.045864
	7	0.063036	0.046566
	8	0.071066	0.051213
Harwich Harbour			
	3	0.146440	0.091632
	4	0.082245	0.057053
	5	0.083553	0.057904
	6	0.076670	0.055459
	7	0.074500	0.053841
	8	0.070371	0.051265
Ipswich			
	1	0.284762	0.171713
	2	0.304852	0.185558
	3	0.349167	0.228142
	4	0.284875	0.172040
	5	0.270898	0.160467
	6	0.277211	0.164196
	7	0.268906	0.158911
	8	0.252363	0.149431
Lerwick			
	3	0.315653	0.215376
	4	0.212414	0.135389
	5	0.199876	0.127675
	6	0.186324	0.118824
	7	0.162005	0.104223
	8	0.185966	0.119354
Poole			
	1	0.298286	0.194397
	2	0.362604	0.255392
	3	0.296445	0.195756
	4	0.289004	0.187775
	5	0.294243	0.191877
	6	0.284823	0.183850
	7	0.265567	0.170698
	8	0.213936	0.134386
Shoreham			
	1	0.366410	0.249697
	2	0.342883	0.227926
	3	0.359644	0.242436
	4	0.354862	0.238668
	5	0.287283	0.182129
	6	0.341403	0.228474
	7	0.178440	0.111286
	8	0.211650	0.131939

Table A4.4-1 (Continued)
Parametric Estimates for Purely Productive Inefficiency

Ports	Years	Purely Productive Inefficiency	
		Half-normal	Exponential
Harwich Dock			
	3	0.139141	0.090889
	4	0.176591	0.114739
	5	0.170513	0.113548
	6	0.202410	0.133894
	7	0.186538	0.125506
Ramsgate			
	3	0.225626	0.142308
	4	0.198213	0.125325
	5	0.150508	0.096527
	6	0.244612	0.164307
	7	0.214231	0.143055
	8	0.193410	0.129400

Notes:

Years 1-8 denote 1983-1990;

Values of inefficiency are percentages beneath the stochastic frontiers under half-normal and exponential assumptions respectively.

Table A4.4-2
Marginal Products of Labour (MPL) and Capital (MPC)
(based on half-normal distribution)

Ports	Years	MPL	MPC
ABP			
	1	1.43062	0.179231E-01
	2	1.21472	0.105213E-01
	5	1.77817	0.319279E-01
	6	1.90920	0.524436E-01
	7	2.20951	0.915199E-01
Bristol			
	3	1.03013	0.794544E-01
	4	1.15387	0.941169E-01
	5	1.12841	0.902326E-01
	6	1.14523	0.924813E-01
	7	1.09408	0.885414E-01
	8	1.13655	0.953135E-01
Clyde			
	1	1.34585	0.133377
	2	1.37206	0.145301
	3	1.39138	0.157923
	4	1.42770	0.169506
	5	1.45919	0.178933
	6	1.42386	0.179893
	7	1.46585	0.194704
	8	1.74309	0.229522
Dover			
	1	1.65445	0.128256
	2	1.61488	0.119867
	3	1.60986	0.115663
	4	1.73754	0.127653
	5	1.62996	0.114432
	6	1.50405	0.997311E-01
	7	1.88101	0.126694
	8	1.95366	0.132954
Felixstowe			
	1	1.42334	0.915503E-01
	2	1.37056	0.875193E-01
	3	1.19742	0.732190E-01
	4	1.24770	0.723439E-01
	5	1.45608	0.843305E-01
	6	1.52677	0.829483E-01
	7	1.40500	0.755580E-01
	8	1.38821	0.766517E-01
Forth			
	1	1.50727	0.124174
	2	1.68611	0.143096
	3	1.75398	0.149335
	4	1.74600	0.157867
	5	1.55804	0.144606
	6	1.70044	0.161747
	7	1.93271	0.187223

Table A4.4-2 (Continued)
Marginal Products of Labour (MPL) and Capital (MPC)
(based on half-normal distribution)

Ports	Years	MPL	MPC
London			
	1	1.44772	0.436041E-01
	2	1.41653	0.441917E-01
	3	1.40383	0.452561E-01
	4	1.58115	0.502643E-01
	5	1.65797	0.838307E-01
	6	1.65557	0.884520E-01
	7	1.57086	0.842141E-01
	8	1.66985	0.949361E-01
Manchester			
	1	1.16223	0.897230E-01
	2	1.14455	0.905268E-01
	3	1.04232	0.828687E-01
	4	1.25086	0.100341
	5	1.27082	0.102102
	6	1.14501	0.801470E-01
	7	0.993801	0.539503E-01
	8	1.15630	0.627442E-01
Medway			
	1	1.42104	0.149798
	2	1.58308	0.160310
	3	1.55249	0.158536
	4	1.38406	0.139731
	5	1.41792	0.140523
	6	1.45635	0.139636
	7	1.45964	0.133791
	8	1.56864	0.140197
Mersey			
	3	1.27170	0.728083E-01
	4	1.31859	0.789821E-01
	5	1.34294	0.802395E-01
	6	1.40995	0.897502E-01
	7	1.34724	0.876316E-01
	8	1.51663	0.102469
Milford Haven			
	1	1.54398	0.106849
	2	1.62110	0.115399
	3	1.89499	0.141784
	4	1.91761	0.157097
	5	1.80367	0.166159
	6	1.94829	0.186016
	7	1.76616	0.232225
	8	1.48538	0.177891
Tees & Hartlepool			
	1	1.61492	0.131416
	2	1.57237	0.129805
	3	1.65826	0.141238
	4	1.75855	0.147398
	5	1.63143	0.137134
	6	1.57337	0.129587
	7	1.76769	0.153223
	8	1.84520	0.154769

Table A4.4-2 (Continued)
Marginal Products of Labour (MPL) and Capital (MPC)
(based on half-normal distribution)

Ports	Years	MPL	MPC
Tyne			
	3	1.32338	0.128717
	4	1.56056	0.164731
	5	1.62179	0.174492
	6	1.62890	0.176547
	7	1.64068	0.180728
	8	1.64189	0.178223
Aberdeen			
	1	2.30555	0.232695
	2	2.31583	0.236607
	3	2.23687	0.207724
	4	2.09901	0.212192
	5	2.13693	0.218981
	6	2.12316	0.228668
	7	2.12126	0.231466
Ardrossan			
	1	1.03498	0.169913
	2	1.09599	0.186569
	3	1.07774	0.179518
	4	1.06299	0.191529
	5	1.07805	0.193556
	6	1.02959	0.188595
	7	1.07559	0.194831
	8	1.18318	0.200378
Blyth			
	3	1.79340	0.233158
	4	1.65999	0.231448
	5	1.24861	0.175393
	6	1.13539	0.155073
	7	1.24172	0.157388
	8	1.44087	0.183716
Boston			
	3	1.45496	0.259868
	4	1.54565	0.298561
	5	1.21038	0.235955
	6	1.41133	0.281927
	8	1.50731	0.240659
BWB			
	3	0.531696	0.339794E-01
	4	0.555624	0.350217E-01
	5	0.486042	0.291818E-01
	6	0.441711	0.240759E-01
	7	0.488127	0.269565E-01
Cromarty Firth			
	3	1.57292	0.132503
	4	1.49871	0.136489
	5	1.14819	0.985559E-01
	6	1.57746	0.139824
	7	1.46189	0.135283
	8	1.40082	0.135710

Table A4.4-2 (Continued)
Marginal Products of Labour (MPL) and Capital (MPC)
(based on half-normal distribution)

Ports	Years	MPL	MPC
Dundee Firth	1	1.55840	0.213982
	2	1.69343	0.222995
	5	1.83342	0.233592
	6	1.79150	0.223446
	7	1.82196	0.201116
	8	1.68834	0.193959
Great Yarmouth	3	2.64301	0.390950
	4	2.75754	0.441971
	7	2.64081	0.477653
	8	2.52169	0.412978
Harwich Harbour	3	2.33079	0.151107
	4	3.03141	0.206025
	5	2.98468	0.207727
	6	2.85121	0.223764
	7	2.47569	0.283943
	8	2.54695	0.302795
Ipswich	1	1.33751	0.150843
	2	1.30231	0.147601
	3	1.20450	0.139847
	4	1.33706	0.154586
	5	1.37537	0.154498
	6	1.36537	0.152137
	7	1.38164	0.157459
	8	1.41363	0.178874
Lerwick	3	1.67337	0.106195
	4	1.97861	0.129521
	5	1.99866	0.135411
	6	2.07094	0.138291
	7	2.18722	0.145972
	8	2.05084	0.138463
Poole	1	1.33893	0.174787
	2	1.24890	0.141266
	3	1.36653	0.159351
	4	1.36049	0.172002
	5	1.35304	0.171503
	6	1.36335	0.177036
	7	1.39498	0.169104
	8	1.52010	0.188334
Shoreham	1	1.39374	0.144897
	2	1.44192	0.150024
	3	1.42006	0.145832
	4	1.45087	0.140008
	5	1.58480	0.157571
	6	1.44668	0.143910

Table A4.4-2 (Continued)
Marginal Products of Labour (MPL) and Capital (MPC)
(based on half-normal distribution)

Ports	Years	MPL	MPC
Shoreham			
	7	1.77345	0.216481
	8	1.72348	0.181451
Harwich Dock			
	3	1.99668	0.744754E-01
	4	1.96136	-0.565418
	5	1.87951	-0.126171
	6	2.07540	-2.14949
	7	2.29354	-3.91729
Ramsgate			
	3	1.77292	0.153343
	4	1.87610	0.156857
	5	2.08093	0.178149
	6	1.74535	0.120778
	7	1.76592	0.131628
	8	1.83939	0.135145

Notes:

Years 1-8 refer to 1983-1990;

Values of MPL and MPC are marginal products of labour and capital on the deterministic kernel of the stochastic frontier.

Table A4.4-3
Scale Elasticity and Inefficiency
(based on half-normal assumption)

Ports	Years	Scale Elasticity	Scale Inefficiency
ABP			
	1	0.875951	0.284516
	2	0.878477	0.274798
	5	0.879934	0.269220
	6	0.873999	0.292075
	7	0.865826	0.324081
Bristol			
	3	0.885311	0.248874
	4	0.892700	0.221582
	5	0.888382	0.237430
	6	0.892185	0.223455
	7	0.887975	0.238940
	8	0.890265	0.230481
Clyde			
	1	0.922236	0.123282
	2	0.923989	0.118125
	3	0.932483	0.094420
	4	0.945479	0.062625
	5	0.949082	0.054847
	6	0.948766	0.055510
	7	0.953210	0.046515
	8	0.940779	0.073466
Dover			
	1	0.879336	0.271506
	2	0.873316	0.294729
	3	0.868770	0.312491
	4	0.872463	0.298047
	5	0.866736	0.320490
	6	0.858177	0.354424
	7	0.860109	0.346733
	8	0.861259	0.342165
Felixstowe			
	1	0.910078	0.161318
	2	0.901888	0.188955
	3	0.877632	0.278039
	4	0.884885	0.250471
	5	0.887663	0.240096
	6	0.887863	0.239354
	7	0.877507	0.278519
	8	0.881740	0.262346
Forth			
	1	0.891221	0.226978
	2	0.894297	0.215799
	3	0.893944	0.217075
	4	0.904390	0.180357
	5	0.906494	0.173231
	6	0.908381	0.166921
	7	0.909491	0.163249
London			
	1	0.903108	0.184746

Table A4.4-3 (Continued)
Scale Elasticity and Inefficiency
(based on half-normal assumption)

Ports	Years	Scale Elasticity	Scale Inefficiency
London			
	2	0.905128	0.177846
	3	0.905621	0.176176
	4	0.907819	0.168791
	5	0.897911	0.202883
	6	0.895299	0.212195
	7	0.894381	0.215496
	8	0.897707	0.203605
Manchester			
	1	0.898052	0.202382
	2	0.900114	0.195126
	3	0.895633	0.210996
	4	0.889788	0.232234
	5	0.887682	0.240024
	6	0.864984	0.327405
	7	0.830754	0.463778
	8	0.829999	0.466758
Medway			
	1	0.940055	0.075204
	2	0.941789	0.071072
	3	0.934904	0.088072
	4	0.928672	0.104787
	5	0.931217	0.097812
	6	0.926980	0.109529
	7	0.918402	0.134860
	8	0.904106	0.181325
Mersey			
	3	0.889104	0.234760
	4	0.893811	0.217556
	5	0.896612	0.207496
	6	0.895943	0.209888
	7	0.898190	0.201894
	8	0.901312	0.190953
Milford Haven			
	1	0.858291	0.353971
	2	0.862059	0.338986
	3	0.868639	0.313007
	4	0.879926	0.269251
	5	0.893220	0.219696
	6	0.897512	0.204295
	7	0.934266	0.089728
	8	0.923262	0.120251
Tees & Hartlepool			
	1	0.899934	0.195759
	2	0.904694	0.179321
	3	0.906177	0.174296
	4	0.921920	0.124221
	5	0.920724	0.127799
	6	0.916969	0.139287
	7	0.907195	0.170878
	8	0.893756	0.217754

Table A4.4-3 (Continued)
Scale Elasticity and Inefficiency
(based on half-normal assumption)

Ports	Years	Scale Elasticity	Scale Inefficiency
Tyne			
	3	0.902578	0.186568
	4	0.915482	0.143941
	5	0.918460	0.134680
	6	0.919929	0.130197
	7	0.920487	0.128511
	8	0.915132	0.145044
Aberdeen			
	1	0.902580	0.186562
	2	0.903980	0.181754
	3	0.893033	0.220373
	4	0.902773	0.185898
	5	0.904309	0.180633
	6	0.910089	0.161284
	7	0.911739	0.155902
Ardrossan			
	1	0.957335	0.038829
	2	0.961390	0.031914
	3	0.959036	0.035850
	4	0.967880	0.022196
	5	0.967308	0.021198
	6	0.969594	0.019910
	7	0.968285	0.021646
	8	0.960902	0.032710
Blyth			
	3	0.934636	0.088766
	4	0.944701	0.064367
	5	0.944521	0.064772
	6	0.941006	0.072923
	7	0.929415	0.102729
	8	0.929517	0.102449
Boston			
	3	0.967614	0.022561
	4	0.978782	0.097466
	5	0.982815	0.006404
	6	0.983872	0.005643
	8	0.954235	0.044545
BWB			
	3	0.892918	0.220791
	4	0.897058	0.205909
	5	0.863705	0.332464
	6	0.843586	0.412739
	7	0.845507	0.405060
Cromarty Firth			
	3	0.881975	0.261451
	4	0.893654	0.218123
	5	0.884988	0.250083
	6	0.890002	0.231448
	7	0.895878	0.210120
	8	0.901697	0.189617

Table A4.4-3 (Continued)
Scale Elasticity and Inefficiency
(based on half-normal assumption)

Ports	Years	Scale Elasticity	Scale Inefficiency
Dundee Firth			
	1	0.937353	0.081844
	2	0.932775	0.093643
	5	0.929210	0.103295
	6	0.926937	0.109652
	7	0.913181	0.151251
	8	0.917309	0.138232
Great Yarmouth			
	3	0.946403	0.060586
	4	0.954931	0.043229
	7	0.968220	0.021734
	8	0.957061	0.039320
Harwich Harbour			
	3	0.835722	0.444094
	4	0.851452	0.381276
	5	0.856451	0.361304
	6	0.874549	0.289941
	7	0.917462	0.137757
	8	0.921579	0.125236
Ipswich			
	1	0.954627	0.043804
	2	0.957583	0.038390
	3	0.944076	0.065781
	4	0.955202	0.042725
	5	0.959754	0.034626
	6	0.961500	0.031734
	7	0.961386	0.031920
	8	0.962237	0.030549
Lerwick			
	3	0.844092	0.410716
	4	0.848791	0.391922
	5	0.854771	0.368010
	6	0.852281	0.377960
	7	0.852291	0.377920
	8	0.854444	0.369316
Poole			
	1	0.932671	0.093920
	2	0.915690	0.143285
	3	0.919214	0.132375
	4	0.928979	0.103933
	5	0.929094	0.103617
	6	0.932295	0.094922
	7	0.925463	0.113857
	8	0.928369	0.105629
Shoreham			
	1	0.908257	0.167333
	2	0.908412	0.166820
	3	0.907099	0.171196
	4	0.899892	0.195906
	5	0.903307	0.184062
	6	0.902943	0.185311

Table A4.4-3 (Continued)
Scale Elasticity and Inefficiency
(based on half-normal assumption)

Ports	Years	Scale Elasticity	Scale Inefficiency
Shoreham			
	7	0.924911	0.115448
	8	0.908765	0.165648
Harwich Dock			
	3	1.08003	0.130063
	4	1.10151	0.200841
	5	1.09647	0.183282
	6	1.12512	0.288668
	7	1.13852	0.341286
Ramsgate			
	3	0.886430	0.244686
	4	0.882331	0.260103
	5	0.885131	0.249546
	6	0.858810	0.351902
	7	0.867936	0.315768
	8	0.866184	0.322669

Notes: The values of scale elasticity are the ones on the deterministic kernel of the stochastic production frontier.

Table A4.4–4
Scale Elasticity and Inefficiency of British Ports
(based on exponential assumption)

Ports	Years	Scale Elasticity	Scale Inefficiency
ABP			
	1	0.914258	0.28282
	2	0.915569	0.27555
	5	0.916182	0.27216
	6	0.913065	0.28946
	7	0.908668	0.31421
Bristol			
	3	0.917559	0.26459
	4	0.921291	0.24431
	5	0.919058	0.25640
	6	0.921054	0.24559
	7	0.918783	0.25789
	8	0.919851	0.25209
Clyde			
	1	0.936269	0.16778
	2	0.936996	0.16430
	3	0.941264	0.14444
	4	0.947952	0.11529
	5	0.949752	0.10789
	6	0.949515	0.10885
	7	0.951709	0.10008
	8	0.945112	0.12735
Dover			
	1	0.914275	0.28272
	2	0.911196	0.29994
	3	0.908864	0.31310
	4	0.910790	0.30223
	5	0.907888	0.31863
	6	0.903449	0.34396
	7	0.904428	0.33835
	8	0.905000	0.33508
Felixstowe			
	1	0.930719	0.19510
	2	0.926555	0.21644
	3	0.914173	0.28329
	4	0.917991	0.26222
	5	0.919413	0.25446
	6	0.919593	0.25349
	7	0.914319	0.28248
	8	0.916448	0.27069
Forth			
	1	0.920457	0.24883
	2	0.921985	0.24059
	3	0.921779	0.24169
	4	0.927139	0.21341
	5	0.928163	0.20812
	6	0.929075	0.20344
	7	0.929595	0.20079

Table A4.4–4 (Continued)
Scale Elasticity and Inefficiency
(based on exponential assumption)

Ports	Years	Scale Elasticity	Scale Inefficiency
London			
	1	0.927660	0.21072
	2	0.928662	0.20556
	3	0.928898	0.20435
	4	0.930007	0.19870
	5	0.924765	0.22582
	6	0.923392	0.23308
	7	0.922923	0.23558
	8	0.924554	0.22692
Manchester			
	1	0.924267	0.22844
	2	0.925283	0.22309
	3	0.922927	0.23555
	4	0.919799	0.25237
	5	0.918659	0.25857
	6	0.906907	0.32421
	7	0.889116	0.42648
	8	0.888527	0.42987
Medway			
	1	0.945384	0.12618
	2	0.946343	0.12207
	3	0.942784	0.13759
	4	0.939579	0.15217
	5	0.940936	0.14593
	6	0.938810	0.15575
	7	0.934457	0.17654
	8	0.927030	0.21397
Mersey			
	3	0.920164	0.25039
	4	0.922511	0.23777
	5	0.923943	0.23016
	6	0.923521	0.23239
	7	0.924641	0.22647
	8	0.926186	0.21836
Milford Haven			
	1	0.901498	0.35515
	2	0.903405	0.34420
	3	0.906799	0.32483
	4	0.912614	0.29199
	5	0.919623	0.25332
	6	0.921753	0.24183
	7	0.941394	0.14385
	8	0.935808	0.16999
Tees & Hartlepool			
	1	0.925118	0.22396
	2	0.927567	0.21119
	3	0.928264	0.20760
	4	0.936434	0.16699
	5	0.935816	0.16995
	6	0.933920	0.17918
	7	0.928751	0.20510

Table A4.4-4 (Continued)
Scale Elasticity and Inefficiency
(based on exponential assumption)

Ports	Years	Scale Elasticity	Scale Inefficiency
Tees & Hartlepool			
	8	0.921745	0.24188
Tyne			
	3	0.925744	0.22068
	4	0.932431	0.18653
	5	0.933961	0.17897
	6	0.934726	0.17523
	7	0.934946	0.17417
	8	0.932042	0.18846
Aberdeen			
	1	0.925022	0.22446
	2	0.925737	0.22071
	3	0.920119	0.25064
	4	0.925131	0.22389
	5	0.925883	0.21994
	6	0.928898	0.20435
	7	0.929802	0.19974
Ardrossan			
	1	0.952549	0.09680
	2	0.954606	0.08896
	3	0.953464	0.09328
	4	0.957952	0.07683
	5	0.957579	0.07814
	6	0.958764	0.07400
	7	0.958066	0.07643
	8	0.954112	0.09082
Blyth			
	3	0.941746	0.14225
	4	0.946943	0.11952
	5	0.946788	0.12017
	6	0.945002	0.12783
	7	0.938855	0.15554
	8	0.938786	0.15586
Boston			
	3	0.957984	0.07672
	4	0.963853	0.05737
	5	0.966063	0.05074
	6	0.966497	0.04948
	8	0.950993	0.10291
BWB			
	3	0.921966	0.24069
	4	0.924105	0.22930
	5	0.906962	0.32390
	6	0.896606	0.38331
	7	0.897584	0.37767
Cromarty Firth			
	3	0.912748	0.29124
	4	0.918803	0.25778
	5	0.914309	0.28254
	6	0.916960	0.26788
	7	0.920059	0.25096

Table A4.4–4 (Continued)
Scale Elasticity and Inefficiency
(based on exponential assumption)

Ports	Years	Scale Elasticity	Scale Inefficiency
Cromarty Firth			
	8	0.923044	0.23493
Dundee Firth			
	1	0.942443	0.13911
	2	0.940000	0.15022
	5	0.938130	0 15893
	6	0.936935	0.16460
	7	0.929981	0.19883
	8	0.932286	0.18725
Great Yarmouth			
	3	0.946621	0.12088
	4	0.951043	0.10271
	7	0.958088	0.07636
	8	0.952268	0.09789
Harwich Harbour			
	3	0.889369	0.42502
	4	0.897549	0.37788
	5	0.900167	0.36280
	6	0.909973	0.30683
	7	0.932703	0.18517
	8	0.934789	0.17493
Ipswich			
	1	0.952767	0.09595
	2	0.954275	0.09021
	3	0.947273	0.11813
	4	0.953024	0.09496
	5	0.955398	0.08602
	6	0.956300	0.08273
	7	0.956213	0.08304
	8	0.956495	0.08202
Lerwick			
	3	0.894070	0.39794
	4	0.896442	0.38426
	5	0.899586	0.36614
	6	0.898267	0.37374
	7	0.898283	0.37364
	8	0.899448	0.36693
Poole			
	1	0.940478	0.14803
	2	0.931736	0.18999
	3	0.933540	0.18104
	4	0.938610	0.15668
	5	0.938632	0.15658
	6	0.940326	0.14872
	7	0.937022	0.16418
	8	0.938527	0.15707
Shoreham			
	1	0.926956	0.21436
	2	0.927018	0.21404
	3	0.926303	0.21776
	4	0.922624	0.23717

Table A4.4–4 (Continued)
Scale Elasticity and Inefficiency
(based on exponential assumption)

Ports	Years	Scale Elasticity	Scale Inefficiency
Harwich Harbour			
	3	1.01617	0.01175
	4	1.02727	0.03306
	5	1.02452	0.02682
	6	1.03947	0.06803
	7	1.04638	0.09269
Ramsgate			
	3	0.915945	0.27347
	4	0.913874	0.28496
	5	0.902034	0.35207
	7	0.906907	0.32421
	8	0.906030	0.32920

Notes: The values of scale elasticity are the ones on the deterministic kernel of the stochastic production frontier.

Appendix 4.5
Parametric Efficiency Estimates: Panel Data Analysis

Table A4.5-1
Parametric Estimates of Purely Productive Inefficiency

Ports	Purely Productive Inefficiency[1]	
	"Cross-sectional" Data[2]	Panel Data
ABP	0.885	0.988
Bristol	0.683	0.547
Clyde	0.796	0.631
Dover	0.872	0.866
Felixstowe	0.813	0.733
Forth	0.870	0.808
London	0.850	0.800
Manchester	0.695	0.582
Medway	0.810	0.672
Mersey	0.797	0.697
Milford Haven	0.802	0.652
Tees & Hartlepool	0.866	0.801
Tyne	0.823	0.682
Aberdeen	0.909	0.889
Ardrossan	0.639	0.407
Blyth	0.752	0.565
Boston	0.777	0.551
BWB	0.386	0.287
Cromarty Firth	0.641	0.444
Dundee Firth	0.836	0.644
Great Yarmouth	0.936	0.940
Harwich Harbour	0.915	0.990
Ipswich	0.748	0.575
Lerwick	0.807	0.723
Poole	0.752	0.554
Shoreham	0.739	0.530
Harwich Dock	0.841	0.845
Ramsgate	0.812	0.682

Notes:

[1] Both ML estimators assume half-normal distribution for inefficiency;

[2] Time averages for each port.

Chapter 5

Productive Efficiency of British Ports
Relative to a Dynamic Frontier

The deviation of port production from the frontier, whether deterministic or stochastic, is hypothesized as either X-inefficiency or technical inefficiency or both. While X-inefficiency is due to motivational deficiencies at both management and worker level, technical inefficiency need not involve any avoidable mistakes in the short run. It may be perfectly rational for a port to stay where it is, since scrapping of existing terminal facilities and equipment would be a wrong decision before the end of their economic lives. However, failures to move from old "vintage" technology to the best-practice technology in the long run may well indicate that the port is not conducive to technological development. With the elapse of time it is also possible for ports to eliminate X-inefficiency. They become more and more efficient at producing even with the existing vintage because of an improvement in internal organisation, or the abolition of restrictive practices, or better trained dock workers and so on. Moreover, in the long run not only does the average technology move towards the best-practice technology, but the best-practice itself moves as well. Efficiency gains over time are thus compounded by the movement towards the frontier by eliminating technical and X-inefficiency, and the shift of the frontier because of technical progress on the frontier. In the previous two chapters we assumed that the production frontier against which port performance is evaluated is fixed. This chapter allows a shift of the production frontier over time and investigates the dynamic dimension of productive performance or progressiveness of British ports.

The pioneering work on measuring dynamic efficiency by invoking an explicit specification of a production function is that of Solow (1957). He demonstrated that the rate of productivity growth could be identified with the rate of technical change, assuming constant returns to scale and competitive markets. From the perspective of frontier function theory, the production function used by Solow represents the average rather than the frontier technology and he implicitly assumed that there is no static inefficiency. Efficiency gains over time are thus solely due to technological advance. Since in this study productive performance is evaluated in the framework of frontier theory, Solow's methodology is unattractive. However, one can redevelop Solow's measure of productivity growth in Farrell's framework. It can be shown that, by substituting the frontier function for the average function, the growth rate of total factor productivity can be more meaningfully interpreted as the rate of technical progress on the frontier (the shift of the frontier function) and the rate of efficiency improvement (the movement towards the shifting frontier).

The theoretical basis of total factor productivity growth measurement in terms of a stochastic frontier function is provided in section 5.1. The dynamic efficiency of British ports is modelled by a dynamic translog production frontier in section 5.2. The construction developed is then applied to the data set of British ports for 1983–1990.

It is found that the structure of the best-practice technology of the British port industry appears to have remained unchanged over this period, and that total factor productivity change came predominantly from efficiency improvement or deterioration.

5.1 Total Factor Productivity and the Frontier Function

Solow (1957) translated the movement in output into the movements in the inputs and the technical progress. The term "(neutral) technical progress" is used as a shorthand for the shift of production function over time representing the change in output that cannot be attributed to the change in inputs, which is synonymous with the growth rate of total factor productivity (δTFP).

While Solow's δTFP is derived from an aggregate production function for a sector or an economy, his methodology certainly applies to, and in fact is more relevant to, a micro decision-making unit. This is because the production function originally refers to a micro unit whereas the existence of aggregate production functions has been widely questioned. To establish Solow's measure at firm level, suppose that a number of firms in an industry share a commonly micro production 33function that changes over time because of technical advance. Thus in the dynamic framework output is a function of time t as well as the usage of inputs:

$$(5.1\text{-}1) \qquad Y_{it} = f(X_{1it}, X_{2it}, t)$$

where subscript *i* denotes production units and *t* denotes time periods.

Following Solow, differentiating Eq(5.1-1) totally with respect to *t* and dividing it by Y_{it} one obtains

$$(5.1\text{-}2) \qquad \frac{1}{Y_{it}}\frac{dY_{it}}{dt} = \frac{X_{1it}}{Y_{it}}\frac{df}{dX_{1it}}\frac{dX_{1it}}{dt}\frac{1}{X_{1it}} + \frac{X_{2it}}{Y_{it}}\frac{df}{dX_{2it}}\frac{dX_{2it}}{dt}\frac{1}{X_{2it}} + \frac{1}{Y_{it}}\frac{df}{dt}$$

This is equivalent to

$$(5.1\text{-}3)\qquad \frac{d\ln Y_{it}}{dt} = \Psi_{lit}\frac{d\ln X1_{it}}{dt} + \Psi_{kit}\frac{d\ln X2_{it}}{dt} + \frac{d\ln f}{dt}$$

where Ψ_{lit} and Ψ_{kit} are the elasticities of output with respect to labour and capital for production unit *i* in time period *t* respectively. In other words, the change in output over time can be segregated into the change in inputs and technical progress. The shift in the production function is Hicks-neutral if dlnf/dt is independent of $X1_{it}$ and $X2_{it}$, namely shifts in the production function leave marginal rates of substitution untouched but simply increase or decrease the output attainable from given inputs. It should be noted that neutrality is only a special case rather than a necessary assumption of Solow's result.

Replacing time series of $d\ln Y_{it}/dt$, $d\ln X1_{it}/dt$, $d\ln X2_{it}/dt$, dlnf/dt by their discrete year-to-year analogues, we get

$$(5.1\text{-}4)\qquad \delta Y_{it} = \Psi_{lit}\delta X1_{it} + \Psi_{kit}\delta X2_{it} + \delta f_{it}$$

where $\delta Y_{it}=\Delta\ln Y_{it}/\Delta t$, $\delta X1_{it}=\Delta\ln X1_{it}/\Delta t$ and so on. Since

$$(5.1\text{-}5)\qquad \delta Y_{it} = \Delta\ln Y_{it}/\Delta t = \ln Y_{it}-\ln Y_{it-1} = \ln(Y_{it}/Y_{it-1})$$

δ signifies relative change in terms of the exponential rate of growth in the value of a variable and Δ signifies absolute change which is the difference in the value of a variable from the previous period to the current period.

Turning Eq(5.1-4) around gives

$$(5.1\text{-}6)\qquad \delta Y_{it} - \Psi_{lit}\delta X1_{it} - \Psi_{kit}\delta X2_{it} = \delta f_{it}$$

If inputs are weighted by their output elasticities, the LHS of Eq(5.1-6) is the growth rate of total factor productivity δTFP_{it} and it is equivalent to the rate of technical progress, i.e.

$$(5.1\text{-}7) \qquad \delta TFP_{it} = \delta f_{it}$$

Solow's work was published in the same year as Farrell's when the idea of frontier functions was largely unknown. From the point of view of the frontier theory, a crucial assumption implicit in Solow's work as in the classical framework of economics is that firms never deviate from the efficiency frontier of the industry. It then follows that efficiency gains over time are brought about only by the shift of the frontier. An interesting question is what δTFP_{it} will look like if we start from a stochastic frontier production function instead of a deterministic average production function expressed in Eq(5.1-1) and carry out similar reasoning as in the Solow's work. Assume that the observed output Y_{it} can deviate from a stochastic frontier with inefficiency and that the error structure is multiplicative so that

$$(5.1\text{-}8) \qquad Y_{it} = F(X_{1it}, X_{2it}, t)EXP(V_{it}-U_{it})$$

where the one-sided error term $U_{it} \geq 0$ represents inefficiency and the symmetrical term V_{it} represents statistical noise. Note that U_{it} and V_{it} differ with *i* and *t* in general. The cross-section variation of U_{it} represents inter-firm efficiency in period *t* and the time-series variation of U_{it} represents inter-period efficiency for firm *i*.

Differentiating Eq(5.1-8) totally with respect to t and dividing by Y_{it} we get

$$(5.1\text{-}9) \qquad \frac{dlnY_{it}}{dt} = \Psi_{1it}\frac{dlnX_{1it}}{dt} + \Psi_{kit}\frac{dlnX_{2it}}{dt} + \frac{dlnF}{dt} + \frac{dV_{it}}{dt} - \frac{dU_{it}}{dt}$$

or

$$(5.1\text{-}10)\quad \frac{d\ln Y_{it}}{dt} - \Psi_{lit}\frac{d\ln X_{1it}}{dt} - \Psi_{kit}\frac{d\ln X_{2it}}{dt} = \frac{d\ln F}{dt} + \frac{dV_{it}}{dt} - \frac{dU_{it}}{dt}$$

which is similar to Eq(5.1-3). But note that $\Psi_{lit}=(X_{1it}/F)(dF/dX_{1it})$ and $\Psi_{kit}=(X_{2it}/F)(dF/dX_{2it})$ are output elasticities with respect to labour and capital on the deterministic kernel of the stochastic frontier. They are characteristics of the frontier rather than the average technology in the industry.

Replacing the time series by their year-to-year analogues yields

$$(5.1\text{-}11)\quad \delta Y_{it} - \Psi_{lit}\delta X_{1it} - \Psi_{kit}\delta X_{2it} = \delta F_{it} + \Delta V_{it} - \Delta U_{it}$$

i.e.

$$(5.1\text{-}12)\quad \delta TFP_{it} = \delta F_{it} + \Delta V_{it} - \Delta U_{it}$$

where δF_{it} is the rate of technical progress on the frontier, ΔV_{it} is the rate of absolute change in exogenous influences, and ΔU_{it} is the rate of absolute change in efficiency. $\Delta U_{it} > 0$ indicates deterioration in efficiency and $\Delta U_{it} < 0$ improvement in efficiency for firm *i* from *t-1* to *t*.

Excluding exogenous influences beyond the control of producers, the growth rate of total factor productivity is given by

$$(5.1\text{-}13)\quad \delta TFP_{it} = \delta F_{it} - \Delta U_{it}$$

In contrast to Eq(5.1-7), total factor productivity growth is translated into the rate of technical progress on the frontier ΔF_{it} and the rate of efficiency improvement $-\Delta U_{it}$. By Eq(5.1-13) one can characterise the following four possible situations of progressiveness in an industry:

(1) a progressive frontier technology co-existent with improvement in efficiency;

(2) a progressive frontier technology co-existent with deterioration in inefficiency;

(3) a static frontier technology co-existent with improvement in efficiency;

(4) a static frontier technology co-existent with deterioration in efficiency.

The progressiveness of the frontier technology may be correlated with the change in efficiency. A highly progressive frontier technology in an industry may lead to deterioration in efficiency of average firms. But there are other driving forces behind efficiency change, such as the demise of restrictive practices, changes in labour-management relationship, improvements in training of labour, etc. Thus the dynamic efficiency of the industry can exhibit any one of these patterns. δTFP_{it} is more meaningful in Eq(5.1-13) than in Eq(5.1-7). Efficiency gains over time depend not only upon expanding production possibilities because of advances in the best-practice technology, but also the extent to which firms succeed in realising the expanded possibility. Actually Solow's δTFP_{it} is only a special case of Eq(5.1-13) when firms always operate on the frontier, i.e. $U_{it} = 0$. This assumption is of course rejected in the frontier theory. A more likely situation when Eq(5.1-13) reduces to Eq(5.1-7) is that efficiency is invariant with time, i.e. $\Delta U_{it} = 0$. The firm's pace of technical progress is just equal to the pace of technical progress on the frontier.

5.2 The Dynamic Frontier Model

As seen in the last chapter the data set has rejected the Cobb–Douglas model in favour of the translog model. To model dynamic efficiency in the industry we again assume that the frontier technology is translog. The model is flexible so that each point of interest has to be separately evaluated. In particular, elasticity of scale and elasticities of output with respect to labour and capital vary with the level of production and factor proportions. To characterise technical progress, the time variable is introduced into parameters of the frontier production function, thus allowing that the frontier technologies not only vary with factor proportions and the level of production but also change with time. Moreover the translog form of technical progress is not necessarily Hicks neutral, enabling us to study the neutrality of technical progress.

For a two–input case a dynamic translog production frontier model may take the form

$$(5.2\text{-}1)\quad \ln Y_{it} = \ln\gamma_0+\rho_0 t+(\alpha_1+\rho_1 t)\ln X1_{it}+(\beta_1+\rho_2 t)\ln X2_{it} \\ +\alpha_2(\ln X1^2_{it}) +\beta_2(\ln X2^2_{it}) +\gamma_1 \ln X1_{it}\ln X2_{it} \\ +V_{it}-U_{it}$$

where

$$\ln\gamma_0+\rho_0 t+(\alpha_1+\rho_1 t)\ln X1_{it}+(\beta_1+\rho_2 t)\ln X2_{it} \\ +\alpha_2(\ln X1^2_{it}) +\beta_2(\ln X2^2_{it}) +\gamma_1 \ln X1_{it}\ln X2_{it}$$

is the logarithm of the deterministic kernel of the stochastic frontier production function in Eq(5.1–8). The dynamic frontier model is different from the static frontier model (4.3–5) by specifying a time trend in the constant and in the parameters of $\ln X1_{it}$ and $\ln X2_{it}$. Unlike the static model, the dynamic model consists of a series of production frontiers corresponding to each time period.

Differentiating the deterministic kernel frontier production function in logarithmic form with respect to t gives the rate of technical progress on the frontier

$$(5.2\text{-}2) \qquad \delta F_{it} = \frac{d\ln F}{dt} = \rho_0+\rho_1 \ln X1_{it}+\rho_2 \ln X2_{it}$$

which varies with the level of production and factor proportions.

The marginal product of labour and capital are found by differentiating Eq(5.2–1) with respect to $X1_{it}$ and $X2_{it}$

$$(5.2\text{-}3) \qquad MPL = (Y_{it}/X1_{it})(\alpha_1+\rho_1 t+2\alpha_2 \ln X1_{it}+\gamma_1 \ln X2_{it})$$

and

$$(5.2\text{-}4) \qquad MPC = (Y_{it}/X2_{it})(\beta_1+\rho_2 t+2\beta_2 \ln X2_{it}+\gamma_1 \ln X1_{it})$$

hence in a competitive market

$$(5.2\text{-}5) \qquad \frac{P_l}{P_c} = \frac{X2_{it}}{X1_{it}} \left\{\frac{\alpha_1+\rho_1 t+2\alpha_2 \ln X1_{it}+\gamma_1 \ln X2_{it}}{\beta_1+\rho_2 t+2\beta_2 \ln X2_{it}+\gamma_1 \ln X1_{it}}\right\}$$

where P_l and P_c are factor prices for $X1$ and $X2$. Recall that Hicks neutrality is associated with that kind of technical progress which leaves factor ratios unchanged if factor prices remain constant. Thus the translog technology is Hicks neutral if the term in the curly brackets of Eq(5.2–5) is constant. This is the case when $\rho_1=0$ and $\rho_2=0$, and under constant returns to scale (CRTS), i.e.

$$\alpha_1+\beta_1 = 1, \quad 2\alpha_2 = -\gamma_1 \quad \text{and} \quad 2\beta_2 = -\gamma_1$$

Thus

$$\text{(5.2-6)} \qquad \frac{P_l}{P_c} = \frac{X_{2it}}{X_{1it}} \left\{ \frac{1-\beta_1+\gamma_1 \ln(X_{2it}/X_{1it})}{\beta_1-\gamma_1 \ln(X_{2it}/X_{1it})} \right\}$$

which yields constant X_{2it}/X_{1it} when P_l/P_k is constant. Hence the CRTS translog technology has Hicks neutral technological progress provided that the parameters for $\ln X_{1it}$ and $\ln X_{2it}$ remain constant over time. The rate of Hicks neutral technological change is given by ρ_0.

From Eq(5.2–3) and Eq(5.2–4) we have output elasticities of labour and capital, i.e.

$$\text{(5.2-7)} \qquad \Psi_{lit} = \alpha_1+\rho_1 t+2\alpha_2 \ln X_{1it}+\gamma_1 \ln X_{2it}$$

and

$$\text{(5.2-8)} \qquad \Psi_{cit} = \beta_1+\rho_2 t+2\beta_2 \ln X_{2it}+\gamma_1 \ln X_{1it}$$

respectively. Both vary with time as well as with the level of production and factor proportions. With no change in X_{1it} and X_{2it} the process of technical progress is labour saving (or capital saving) if $\rho_1<0$ (or $\rho_2<0$)

The returns to scale properties are given by the scale elasticity function,

$$\text{(5.2-9)} \quad \Psi_s = (\alpha_1+\rho_1 t)+(\beta_1+\rho_2 t)+(2\alpha_2+\gamma_1)\ln X_{1it}+(2\beta_2+\gamma_1)\ln X_{2it}$$

which varies with time as well as with the level of production and factor proportions.

In order to calculate δTFP_{it} in Eq(5.1–13) for each observation, two time series are needed: δF_{it} and ΔU_{it} efficiency improvement. δF_{it} can be given by Eq(5.2–2). A better estimate of this may be obtained by averaging the current period's value and the previous period's value. Thus

$$(5.2\text{-}10) \qquad \delta F_{it} = (2\rho_0+\rho_1 \ln X_{1t-1} \ln X1_t+\rho_2 \ln X2_{t-1}X2_t)/2$$

Let U_{it-1} and U_{it} denote the inefficiency level (the shortfall of output below the stochastic frontier in percentage) for port *i* in period *t*–1 and *t*. The rate of efficiency change for the port in period *t* is given by the difference from period *t–1*, i.e.

$$(5.2\text{-}11) \qquad \Delta U_{it} = U_{it} - U_{it-1}$$

Recall that $\Delta U_{it}>0$ implies a deterioration in efficiency and $\Delta U_{it}<0$ an improvement in efficiency.

The growth rate of total factor productivity δTFP_{it} for port *i* in period *t* is compounded from the rate of technical progress on the frontier δF_{it} and the rate of efficiency improvement ΔU_{it}, namely

$$\begin{aligned} (5.2\text{-}12) \qquad \delta TFP_{it} &= \Delta F - \Delta U_{it} \\ &= (2\rho_0+\rho_1 \ln(X_{1\,it-1}X1_{it})+\rho_2 \ln(X2_{it-1}X2_{it})/2 \\ &\quad + U_{it-1}-U_{it} \end{aligned}$$

5.3 Estimates of Dynamic Efficiency

The ML as well as the OLS estimates of the dynamic translog frontier function from the cross-sectional and time-series data of inputs and output for 28 British ports during the period 1983-1990 are set out in Table 5.3-1. Again both half-normal and exponential distributions were specified for the inefficiency term.

Table 5.3-1 The Dynamic Translog Frontier of British Ports 1983-1990

Estimator	OLS	ML	
Error Specification		Half-Normal	Exponential
R^2	0.957	-	-
$\bar{R}^2$	0.955	-	-
Residual-squared	12.340	-	-
Log-likelihood	-10.340	-6.177	0.276
Constant	-2.594	0.080	0.419
	(1.162)	(1.133)	(1.015)
Trend	0.051	0.034	0.025
	(0.075)	(0.075)	(0.067)
$\log X_1$	0.640	0.538	0.631
	(0.180)	(0.173)	(0.159)
Trend	0.006	0.007	0.004
	(0.018)	(0.015)	(0.013)
$\log X_2$	1.040	0.641	0.441
	(0.264)	(0.251)	(0.247)
Trend	-0.009	-0.008	-0.005
	(0.019)	(0.016)	(0.014)
$(\log X_1)^2$	0.115	0.091	0.081
	(0.021)	(0.019)	(0.018)
$(\log X_2)^2$	0.043	0.046	0.054
	(0.019)	(0.017)	(0.016)
$\log X_1 \log X_2$	-0.195	-0.149	-0.141
	(0.048)	(0.043)	(0.028)
$\lambda=\sigma_u/\sigma_v$		1.918	-
		(0.585)	-
σ		0.361	-
		(0.029)	-
θ		-	5.540
		-	(0.738)
σ_v		-	0.173
		-	(0.018)

Note: Standard errors of the estimator are in the parentheses below the parameter estimates.

The structural change of the production frontier is indicated by the estimated trends. The positive estimate of ρ_0 implies the shifts in the production frontier. Since the estimate is positive for ρ_1 and negative for ρ_2, the kernel output elasticity of labour increased and the kernel output elasticity of capital decreased over time. The observed technical change can in this sense be characterised as capital saving. However, the time trends are weak in all cases. For an average port, the characteristics of technical progress on the frontier are presented in Table 5.3-2. The output elasticity with respect to labour is about 2.5 times as high as with respect to capital. The frontier technology exhibits decreasing returns to scale. Although the scale elasticity declined gradually and there were changes in the output elasticity in the direction of capital saving, the structure was fairly stable throughout the whole period. As far as the average port is concerned, the rate of technical progress on the frontier is 1.5% per year, which is rather low.

Table 5.3-2 The Best-Practice Technology of British Ports 1983-1990

Year	1983	1984	1985	1986	1987	1988	1989	1990
	Output Elasticities							
Labour	0.613	0.620	0.627	0.634	0.641	0.648	0.655	0.662
Capital	0.275	0.265	0.259	0.251	0.243	0.235	0.227	0.219
	Scale Elasticity							
	0.888	0.887	0.886	0.885	0.884	0.883	0.882	0.881
	Rate of Technical Progress on the Frontier							
	1.5%							

Note: These figures refer to technical characteristics of an average port (an arbitary observation with arithmetic average value of inputs and output in the industry.

Cutting the estimated dynamic frontier production function with a vertical plane through the origin along the average factor ray (a ray corresponding to the average factor ratio), one obtains the series of production frontiers corresponding to each year during 1983–1990. The graph also gives the impression that the shifts in production frontier are not pronounced during this period.

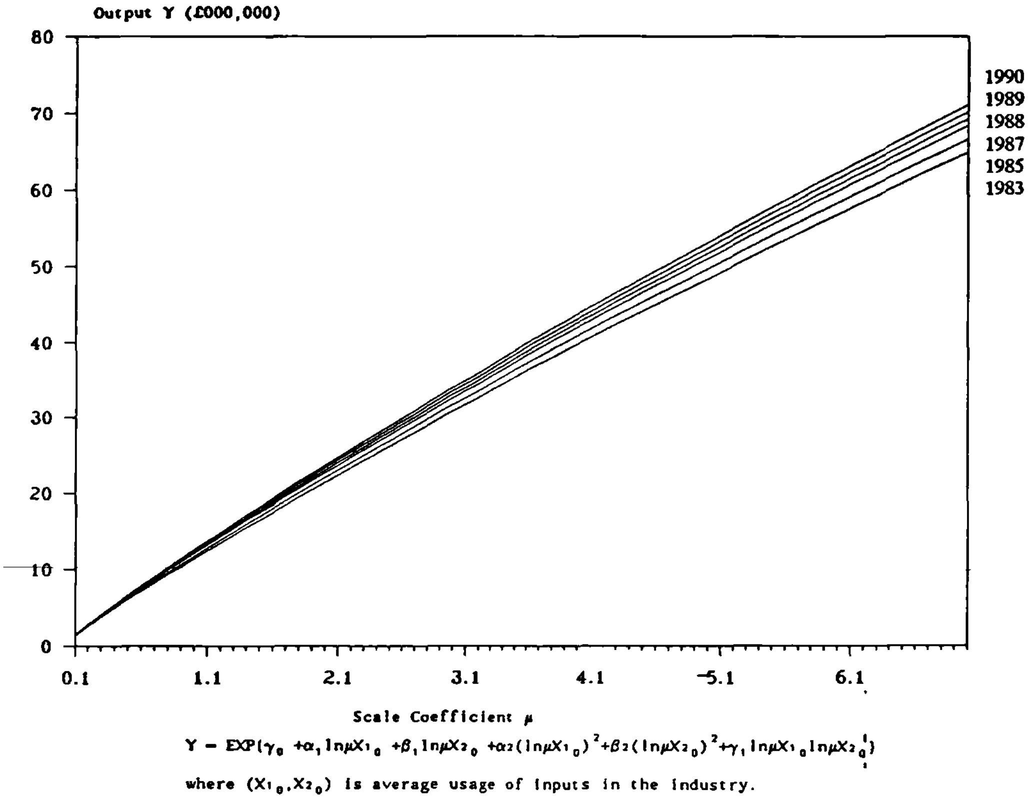


Fig 5.3–1 Shifts of the Production Frontier in the British Port Industry 1983–90
Note: The stochastic frontier model is based on exponential assumption.

A joint significance test of the trend parameters in the dynamic translog model Eq(5.2–1) was performed. If $\rho_0=\rho_1=\rho_2=0$, then the dynamic (unrestrictive) frontier model reduces to the static (restrictive) frontier model Eq(4.3–5) used in chapter 4. The joint significance test is thus equivalent to the test of the adequacy of the restrictions. For the half-normal distribution, the maximised value of log-likelihood is increased from −8.064 for the static model to −6.177 for the dynamic model. For the exponential distribution, the maximised value of log-likelihood is increased from −1.758 to 0.276 accordingly. The value of the generalised likelihood-ratio is 3.8 in the half-normal case and 3.0 in the exponential case. From the chi-square table with 3 degree of freedom we find that the 5% point is 7.81. Thus we reject the joint significance of the trends. We also reject the hypothesis that the static model is not an appropriate representation of the production frontier for the whole period. Being consistent with this, none of the ML parameter estimates of time trends are significantly different from zero. However, all other estimated parameters in the dynamic model are highly significant.

The testing procedure conducted above could be questioned. Since the data set contains a large number of cross-sectional units but only a few periods, cross-sectional variation could overweight time-series variation so that the time trend is concealed. A testing procedure against this suspicion is not available. In order to detect any disguised shift in the production frontier, we fit the static model Eq(4.3-5) for 1983-1984, 1985-1986, 1987-1988, and 1989-1990. If there were any significant time trend, the parameter estimates would be likely to vary consistently from year to year. The results were messy. No consistent shifts in the production frontier were found. Moreover, in these smaller samples the problem of multicollinearity comes back, which makes the parameter estimates imprecise. Table 5.3-2 shows the parameter estimates of the production frontiers for 1983-1986, 1987-1990, and 1983-1990. There do not seem to have been significant changes in the structure, although we cannot make this judgement on certain significance level without a proper sample test.

Table 5.3-3 The Production Frontiers 1985-1990

	Constant	$LogX_1$	$LogX_2$	$LogX_1^2$	$LogX_2^2$	$LogX_1 LogX_2$
1983-1986	0.42	0.72	0.32	0.06	0.07	-0.15
	(2.04)	(0.33)	(0.15)	(0.03)	(0.04)	(0.05)
1987-1990	0.73	0.62	0.40	0.10	0.05	-0.15
	(1.39)	(0.24)	(0.31)	(0.03)	(0.03)	(0.06)
1983-1990	0.62	0.69	0.37	0.08	0.06	-0.14
	(1.01)	(0.18)	(0.26)	(0.02)	(0.02)	(0.04)

Note: The one-sided term is assumed to be exponential.

Estimated productive inefficiencies (purely productive inefficiencies) for each port against each year's frontier in the exponential case are plotted against the ports over time in Fig 5.3-2. The picture is very similar to time plot of estimated efficiencies derived from the static model (not shown). In fact the efficiency estimates derived from both models are close. Both suggest that average British ports are about 25% inefficient under the half-normal distributional assumption and 18% inefficient under the exponential distributional assumption.

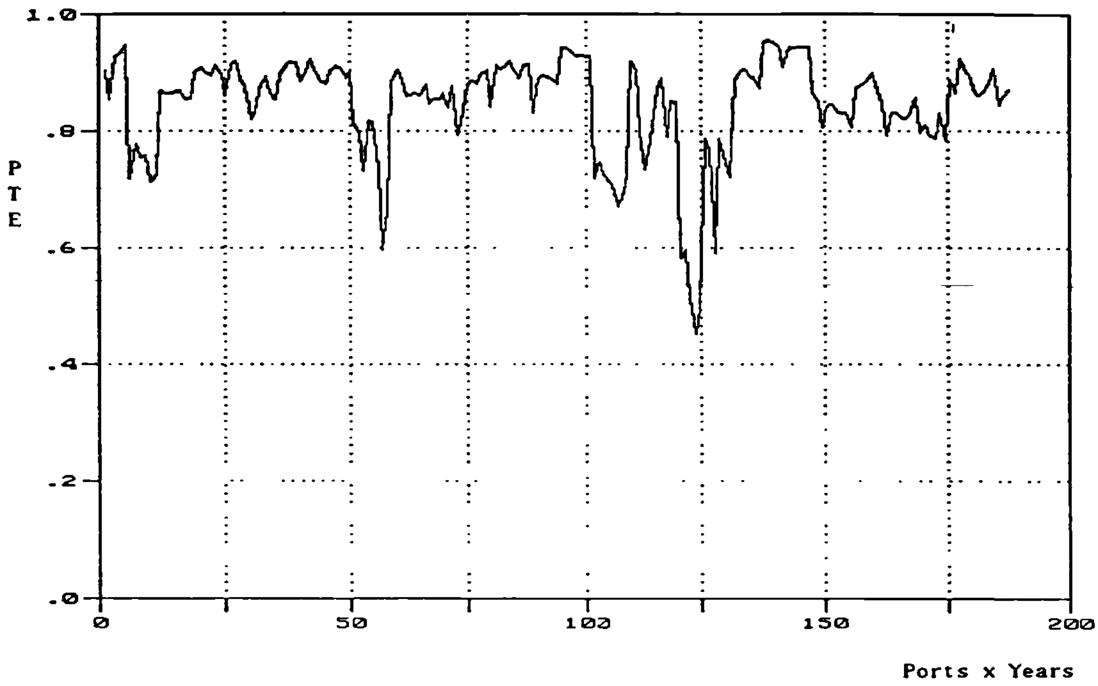


Fig 5.3-2 Pure Productive Efficiency of British Ports Relative to a Dynamic Frontier (exponential) 1983-90

The rate of technical progress on the frontier which can possibly be achieved given factor proportions and the level of production for individual ports were computed in accordance with Eq(5.2-10). The results are presented in Table A5.3-1 of Appendix 5.3 to this chapter and plotted against ports and years in Fig 5.3-3. What can be seen is a picture of a close-to-zero rate of technical progress on the frontier over time regardless of port size. The picture is consistent with the results described above.

Given the estimates for inefficiency one can easily work out the rate of change in efficiency for individual ports in accordance with Eq(5.2–11). The results are presented in Table A5.3–1 and plotted in Fig 5.3–4. In contrast to the rate of technical progress on the frontier, the rate of efficiency change is fairly dynamic. The latter indicates frequent efficiency improvement or deterioration from port to port and from time to time. Since firms tend to raise technical efficiency over time, these moves towards and off the production frontier are likely to reflect the instability of X–efficiency over time.

Given ΔU_{it} and δF_{it}, the estimates of δTFP for individual ports can now be computed in accordance with Eq(5.2–12). The results are also given in Table A5.3–1 and plotted in Fig 5.3–5. Given that the rate of technical progress on the frontier is low and stable, the growth rate of total factor productivity mainly mirrors the rate of efficiency improvement, implying that efficiency gains over time for British ports during this period were brought about mainly by the movement towards the frontier rather than by a shift of the frontier.

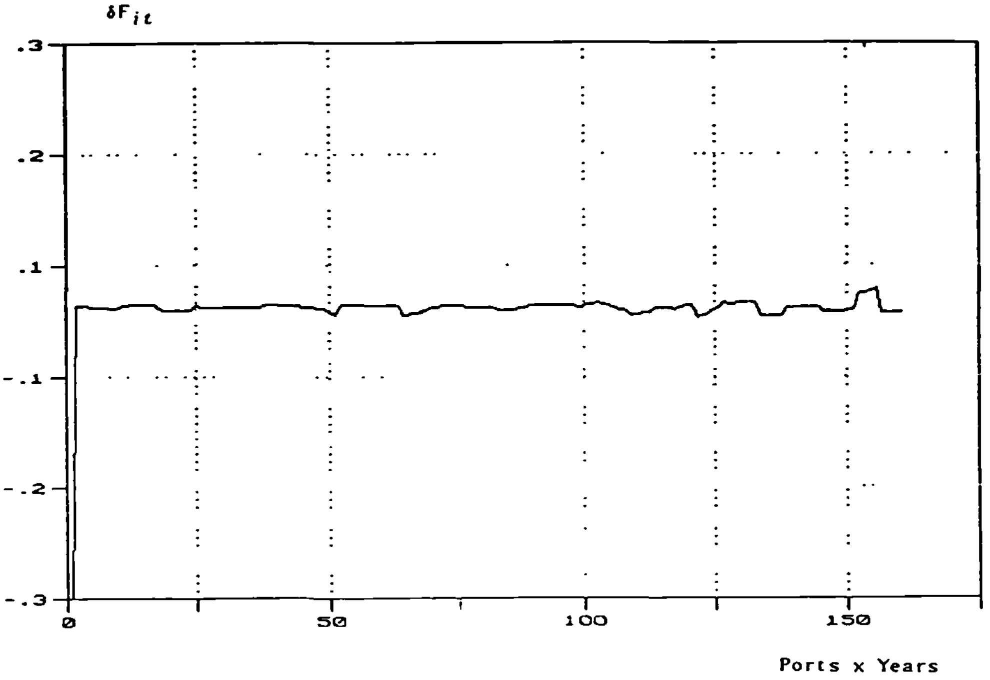


Fig 5.3-3 Technical Progress on the Frontier of the British Ports 1983–1990

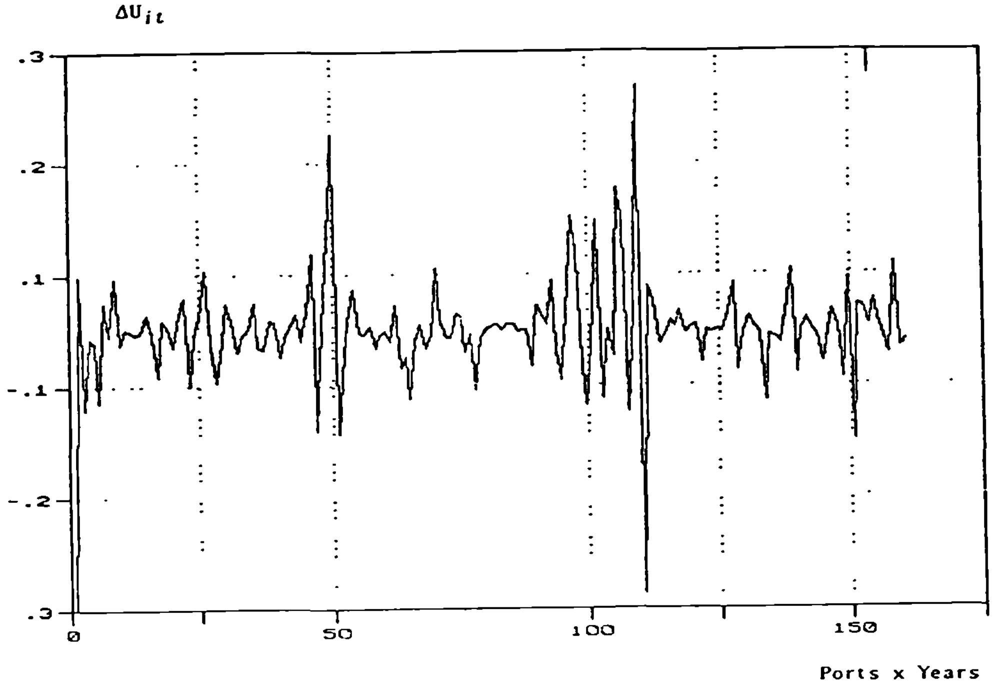


Fig 5.3-4 Efficiency Improvement of British Ports 1983–90

Note: The inefficiency component is assumed to be exponential

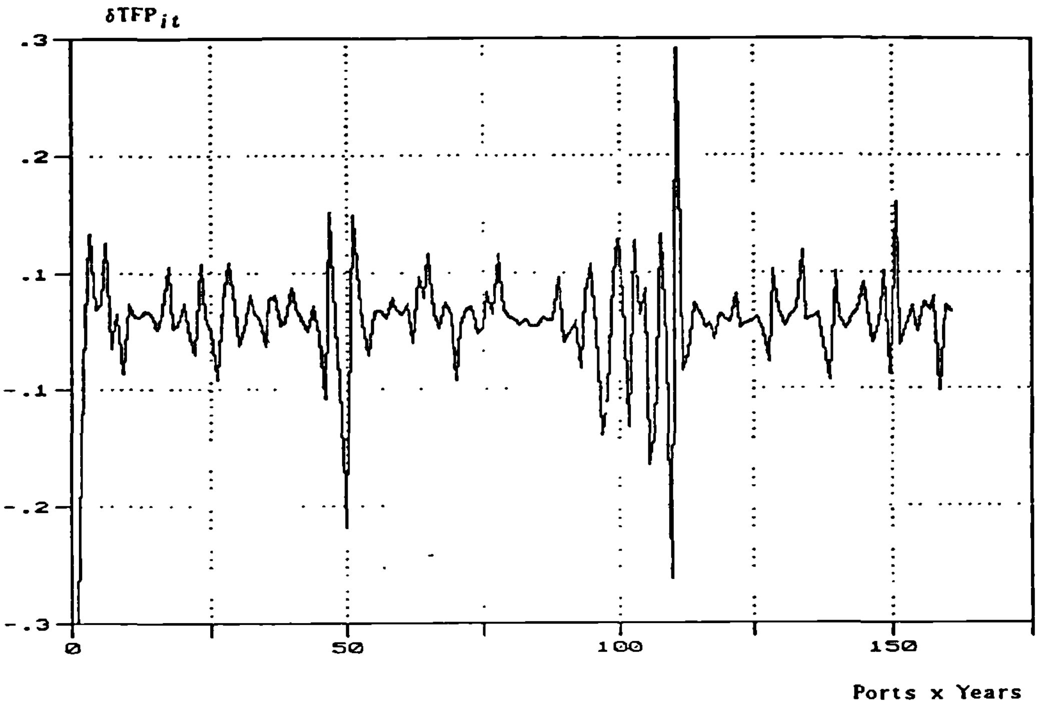


Fig 5.3–5 Total Factor Productivity Growth of British Ports 1983–90

Appendix 5.3 Estimates of Dynamic Efficiency

Table A5.3-1
Efficiency Improvement, Technical Progress and Total Factor Productivity

Port	Year	Technical Progress δF	Efficiency Deterioration ΔU	Total Factor Productivity Growth δTFP
ABP				
1.00000	2	0.180046E-01	0.859837E-01	-0.679790E-01
1.00000	5	0.181048E-01	-0.123359	0.141464
1.00000	6	0.173952E-01	-0.144778E-01	0.318730E-01
1.00000	7	0.158135E-01	-0.213316E-01	0.371451E-01
Bristol				
2.00000	4	0.144262E-01	-0.683401E-01	0.827663E-01
2.00000	5	0.145297E-01	0.263633E-01	-0.118336E-01
2.00000	6	0.145371E-01	-0.317514E-03	0.148546E-01
2.00000	7	0.143908E-01	0.485657E-01	-0.341749E-01
2.00000	8	0.138586E-01	-0.112610E-01	0.251196E-01
Clyde				
3.00000	2	0.186992E-01	0.360353E-02	0.150957E-01
3.00000	3	0.190343E-01	0.569320E-02	0.133411E-01
3.00000	4	0.205800E-01	0.701115E-03	0.198788E-01
3.00000	5	0.218198E-01	0.144580E-02	0.203740E-01
3.00000	6	0.218580E-01	0.278455E-01	-0.598752E-02
3.00000	7	0.218950E-01	-0.280502E-02	0.247000E-01
3.00000	8	0.207386E-01	-0.875861E-01	0.108325
Dover				
4.00000	2	0.118114E-01	0.127314E-01	-0.920005E-03
4.00000	3	0.110073E-01	0.564285E-02	0.536450E-02
4.00000	4	0.109960E-01	-0.238244E-01	0.348204E-01
4.00000	5	0.109570E-01	0.241378E-01	-0.131809E-01
4.00000	6	0.982667E-02	0.412858E-01	-0.314592E-01
4.00000	7	0.920589E-02	-0.793121E-01	0.885180E-01
4.00000	8	0.939349E-02	-0.660188E-02	0.159954E-01
Felixstowe				
5.00000	2	0.188267E-01	0.216228E-01	-0.279612E-02
5.00000	3	0.164848E-01	0.676919E-01	-0.512071E-01
5.00000	4	0.154454E-01	-0.130973E-01	0.285426E-01
5.00000	5	0.163890E-01	-0.731934E-01	0.895824E-01
5.00000	6	0.167511E-01	-0.148293E-01	0.315804E-01
5.00000	7	0.161671E-01	0.354271E-01	-0.192599E-01
5.00000	8	0.156862E-01	0.214626E-01	-0.577643E-02
Forth				
6.00000	2	0.145532E-01	-0.340533E-01	0.486065E-01
6.00000	3	0.146325E-01	-0.697260E-02	0.216051E-01
6.00000	4	0.153738E-01	0.710882E-02	0.826499E-02
6.00000	5	0.162509E-01	0.522820E-01	-0.360311E-01
6.00000	6	0.163650E-01	-0.286714E-01	0.450364E-01
6.00000	7	0.164129E-01	-0.358206E-01	0.522335E-01

Table A5.3-1 (Continued)
Efficiency Improvement, Technical Progress and Total Factor Productivity

Port	Year	Technical Progress δF	Efficiency Deterioration ΔU	Total Factor Productivity Growth δTFP
London				
7.00000	2	0.202288E-01	0.208725E-01	-0.643698E-03
7.00000	3	0.203341E-01	0.150675E-01	0.526654E-02
7.00000	4	0.204803E-01	-0.423707E-01	0.628510E-01
7.00000	5	0.195699E-01	-0.193680E-01	0.389379E-01
7.00000	6	0.182610E-01	0.495049E-02	0.133105E-01
7.00000	7	0.179318E-01	0.269992E-01	-0.906734E-02
7.00000	8	0.179904E-01	-0.140339E-01	0.320243E-01
Manchester				
8.00000	2	0.166233E-01	0.250039E-01	-0.838064E-02
8.00000	3	0.162615E-01	0.817287E-01	-0.654673E-01
8.00000	4	0.151323E-01	-0.117777	0.132909
8.00000	5	0.141841E-01	0.122651E-02	0.129575E-01
8.00000	6	0.119658E-01	0.845732E-01	-0.726074E-01
8.00000	7	0.695397E-02	0.138596	-0.131642
8.00000	8	0.347917E-02	-0.896882E-01	0.931673E-01
Medway				
9.00000	2	0.217941E-01	-0.389630E-01	0.607572E-01
9.00000	3	0.214691E-01	0.149758E-01	0.649328E-02
9.00000	4	0.203908E-01	0.687238E-01	-0.483329E-01
9.00000	5	0.201812E-01	-0.106710E-02	0.212484E-01
9.00000	6	0.202232E-01	-0.719690E-02	0.274201E-01
9.00000	7	0.193979E-01	0.280777E-02	0.165901E-01
9.00000	8	0.175441E-01	-0.390667E-01	0.566108E-01
Mersey				
10.0000	4	0.171093E-01	-0.494452E-02	0.220539E-01
10.0000	5	0.175635E-01	0.276239E-02	0.148011E-01
10.0000	6	0.175821E-01	-0.174219E-01	0.350039E-01
10.0000	7	0.175092E-01	0.407489E-01	-0.232397E-01
10.0000	8	0.177692E-01	-0.539935E-01	0.717628E-01
Milford Haven				
11.0000	2	0.227470E-02	-0.361119E-01	0.383866E-01
11.0000	3	0.306321E-02	-0.105631	0.108694
11.0000	4	0.452481E-02	-0.173443E-01	0.218691E-01
11.0000	5	0.680875E-02	0.772209E-02	-0.913344E-03
11.0000	6	0.837839E-02	-0.317802E-01	0.401586E-01
11.0000	7	0.128170E-01	-0.264528E-02	0.154623E-01
11.0000	8	0.163016E-01	0.102044	-0.857427E-01
Tees & Hartlepool				
12.0000	2	0.168080E-01	0.160665E-01	0.741484E-03
12.0000	3	0.171929E-01	-0.114239E-01	0.286168E-01
12.0000	4	0.185823E-01	-0.858904E-02	0.271713E-01
12.0000	5	0.198681E-01	0.339611E-01	-0.140930E-01
12.0000	6	0.195278E-01	0.221844E-01	-0.265658E-02
12.0000	7	0.182585E-01	-0.449986E-01	0.632572E-01
12.0000	8	0.159894E-01	-0.124222E-01	0.284117E-01
Tyne				
13.0000	5	0.167405E-01	-0.995319E-02	0.266937E-01
13.0000	6	0.171096E-01	0.572661E-02	0.113830E-01
13.0000	7	0.171692E-01	0.606583E-02	0.111034E-01
13.0000	8	0.164047E-01	0.105053E-01	0.589949E-02

Table A5.3-1 (Continued)
Efficiency Improvement, Technical Progress and Total Factor Productivity

Port	Year	Technical Progress δF	Efficiency Deterioration ΔU	Total Factor Productivity Growth δTFP
Aberdeen				
14.0000	2	0.118273E-01	0.868075E-03	0.109592E-01
14.0000	3	0.110761E-01	0.117367E-01	-0.660578E-03
14.0000	4	0.110062E-01	0.128193E-01	-0.181306E-02
14.0000	5	0.118460E-01	-0.104829E-02	0.128943E-01
14.0000	6	0.124388E-01	0.176653E-02	0.106723E-01
14.0000	7	0.132037E-01	0.187393E-02	0.113298E-01
Ardrossan				
15.0000	2	0.185123E-01	-0.355024E-01	0.540147E-01
15.0000	3	0.187194E-01	0.282918E-01	-0.957240E-02
15.0000	4	0.192516E-01	0.155084E-01	0.374324E-02
15.0000	5	0.196674E-01	0.708759E-02	0.125798E-01
15.0000	6	0.196826E-01	0.483519E-01	-0.286693E-01
15.0000	7	0.197331E-01	-0.168602E-01	0.365933E-01
15.0000	8	0.187193E-01	-0.473430E-01	0.660623E-01
Blyth				
16.0000	4	0.185195E-01	0.322170E-01	-0.136974E-01
16.0000	5	0.192352E-01	0.180527	-0.161292
16.0000	6	0.188680E-01	0.864516E-01	-0.675835E-01
16.0000	7	0.173737E-01	-0.445719E-01	0.619456E-01
16.0000	8	0.159170E-01	-0.912310E-01	0.107148
Boston				
17.0000	4	0.215150E-01	-0.279325E-01	0.494475E-01
17.0000	5	0.231879E-01	0.168008	-0.144821
17.0000	6	0.236414E-01	-0.923287E-01	0.115970
17.0000	8	0.207065E-01	0.117955E-02	0.195269E-01
BWB				
18.0000	4	0.172583E-01	-0.163474E-01	0.336057E-01
18.0000	5	0.149614E-01	0.802368E-01	-0.652753E-01
18.0000	6	0.106962E-01	0.684558E-01	-0.577596E-01
18.0000	7	0.921047E-02	-0.688878E-01	0.780983E-01
Cromarty Firth				
19.0000	4	0.355447E-02	0.162539E-01	-0.126994E-01
19.0000	5	0.381407E-02	0.228367	-0.224553
19.0000	6	0.358331E-02	-0.257258	0.260841
19.0000	7	0.471618E-02	0.462527E-01	-0.415366E-01
19.0000	8	0.577295E-02	0.286204E-01	-0.228474E-01
Dundee Firth				
20.0000	2	0.151290E-01	-0.228053E-01	0.379343E-01
20.0000	5	0.142588E-01	-0.106683E-01	0.249271E-01
20.0000	6	0.136816E-01	0.185231E-01	-0.484142E-02
20.0000	7	0.125684E-01	0.388083E-02	0.868752E-02
20.0000	8	0.123333E-01	0.330432E-01	-0.207099E-01
Great Yarmouth				
21.0000	4	0.161637E-01	-0.523841E-02	0.214021E-01
21.0000	7	0.183378E-01	0.711144E-02	0.112264E-01
21.0000	8	0.187349E-01	0.110965E-01	0.763845E-02
Harwich Harbour				
22.0000	4	-0.199720E-02	-0.677639E-01	0.657667E-01
22.0000	5	-0.101883E-03	0.121380E-02	-0.131569E-01

Table A5.3-1 (Continued)
Efficiency Improvement, Technical Progress and Total Factor Productivity

Port	Year	Technical Progress δF	Efficiency Deterioration ΔU	Total Factor Productivity Growth δTFP
Harwich Harbour				
22.0000	6	0.270151E-02	-0.649609E-02	0.919760E-02
22.0000	7	0.961039E-02	0.160290E-02	0.800749E-02
22.0000	8	0.144698E-01	-0.220375E-02	0.166736E-01
Ipswich				
23.0000	2	0.236874E-01	0.326528E-01	-0.896544E-02
23.0000	3	0.227252E-01	0.617746E-01	-0.390494E-01
23.0000	4	0.224896E-01	-0.500136E-01	0.725032E-01
23.0000	5	0.238498E-01	0.173488E-02	0.221149E-01
23.0000	6	0.244164E-01	0.236925E-01	0.723833E-03
23.0000	7	0.245046E-01	0.774264E-02	0.167620E-01
23.0000	8	0.242405E-01	-0.349754E-02	0.277380E-01
Lerwick				
24.0000	4	-0.383738E-03	-0.106777	0.106394
24.0000	5	0.510700E-03	-0.129539E-01	0.134646E-01
24.0000	6	0.840396E-03	-0.136814E-01	0.145218E-01
24.0000	7	0.594671E-03	-0.248542E-01	0.254488E-01
24.0000	8	0.889054E-03	0.257073E-01	-0.248182E-01
Poole				
25.0000	2	0.150879E-01	0.789325E-01	-0.638446E-01
25.0000	3	0.139840E-01	-0.569935E-01	0.709774E-01
25.0000	4	0.151140E-01	0.148055E-02	0.136335E-01
25.0000	5	0.159213E-01	0.162385E-01	-0.317197E-03
25.0000	6	0.162050E-01	0.182673E-02	0.143783E-01
25.0000	7	0.163690E-01	-0.974506E-02	0.261140E-01
25.0000	8	0.164437E-01	-0.459928E-01	0.624364E-01
Shoreham				
26.0000	2	0.914458E-02	-0.168628E-01	0.260074E-01
26.0000	3	0.895141E-02	0.243654E-01	-0.154140E-01
26.0000	4	0.825036E-02	0.207898E-02	0.617138E-02
26.0000	5	0.800418E-02	-0.640548E-01	0.720589E-01
26.0000	6	0.845771E-02	0.618486E-01	-0.533908E-01
26.0000	7	0.106848E-01	-0.163499	0.174184
26.0000	8	0.114009E-01	0.392471E-01	-0.278462E-01
Harwich Dock				
27.0000	4	0.414662E-01	0.422682E-01	-0.801943E-03
27.0000	5	0.425964E-01	0.115905E-01	0.310059E-01
27.0000	6	0.445895E-01	0.561657E-01	-0.115761E-01
27.0000	7	0.483557E-01	0.929630E-02	0.390594E-01
Ramsgate				
28.0000	4	0.617144E-02	-0.244711E-01	0.306425E-01
28.0000	5	0.613728E-02	-0.462681E-01	0.524054E-01
28.0000	6	0.471131E-02	0.966053E-01	-0.918939E-01
28.0000	7	0.410027E-02	-0.272607E-01	0.313610E-01
28.0000	8	0.504733E-02	-0.197708E-01	0.248181E-01

Notes:

$\delta TFP_{it} = \delta F_{it} - \Delta U_{it}$.

U_{it} is assumed to be exponential.

Chapter 6

Efficiency and Port Ownership: Empirical Evidence

The empirical analyses of the previous three chapters have revealed wide efficiency differentials across British ports. This naturally turns our attention to the possible factors that may be, either individually or in combination, the causes of inefficiency and whether these therefore can be seen as focal points for action to bring efficiency to higher levels. But we cannot pretend to trace in any detail the influence and impact on efficiency differentials of the plethora of factors, institutional, technical, economic and physical, which determined the comparative efficiency ratios that have been measured. Such an exhaustive enquiry would require a port–by–port investigation and should be a subject of another study. Our focus is the influence of port ownership. Given the data available, and limited space, we shall also attempt to test some hypotheses on the association between productive efficiency on the one hand and the National Dock Labour Scheme, port size, capital intensity and modes of operation/types of cargo on the other. These hypotheses are important for both public and private policy reasons.

Price–independent efficiency in this study has been decomposed in a suggestive way. We discovered that, among the sources of inefficiency in this industry, purely productive inefficiency and scale inefficiency are the main ones. There has been little evidence of congestive inefficiency. Furthermore productivity growth over time was mainly identified with efficiency improvement while the best–practice technology remained largely unchanged. We begin, in section 6.1, by investigating the influence on purely productive efficiency of port ownership and other factors of interest, and then proceed to scale efficiency in section 6.2 and dynamic efficiency in section 6.3. In the final section conclusions are drawn for the whole study.

6.1 Determinants of Purely Productive Inefficiency

One of the most important ways that British port producers depart from the efficiency frontier is purely productive inefficiency. British ports were about 83% efficient in the exponential case and 78% efficient in the half-normal case relative to the stochastic frontier of the industry during 1983–1990. The average value of PTE is 71% relative to the deterministic frontier.

Non-price productive inefficiency results from failures to maximise output obtainable from a certain input level given the factor ratio, or from failures to minimise inputs in producing a certain output level given the output mix. PTE refers to the kind of failure that can be attributed neither to non-optimal scale nor to congestion in technology. Two hypothesized reasons for this are X-inefficiency and technical inefficiency. The questions to be addressed in this section are as follows: (i) how and to what extent can X-inefficiency and technical inefficiency be explained by port ownership and the labour scheme? (ii) Can the best-practice technology be correlated with port size, capital intensity and modes of operation/cargo types? (iii) To what extent and how does the level of inefficiency relate to demand conditions?

Ownership

Table 6.1-1 shows both parametric (exponential) and non-parametric (input-based) measures of purely productive efficiency (PTE) for 13 major British ports (a classification adopted by the British Ports Federation) during the period from 1985 to 1990. For each port parametric estimates are given in the first row and non-parametric estimates in the second row. Both measures are unified to represent the percentage of efficiency. The last column is the 6-year geometric average values of PTE measures. The 13 ports are ranked in terms of average parametric measures. The ownership status of each port before 1990 is also indicated.

Table 6.1-1 PTE Scores of Major British Ports

		1985	1986	1987	1988	1989	1990	Average[1]
ABP	private	-	-	0.93	0.93	0.95	-	0.94[2]
		-	-	1.00	0.61	1.00	-	0.85[3]
Forth	trust	0.91	0.91	0.89	0.91	0.93	-	0.91
		1.00	1.00	0.88	0.85	0.90	-	0.92
Tees & Hartlepool	trust	0.91	0.92	0.91	0.90	0.92	0.92	0.91
		1.00	1.00	0.95	0.76	0.85	0.74	0.88
Dover	trust	0.88	0.91	0.89	0.87	0.92	0.92	0.90
		1.00	1.00	1.00	1.00	1.00	0.51	0.90
London	trust	0.88	0.90	0.90	0.90	0.90	0.91	0.90
		1.00	1.00	0.95	0.89	1.00	1.00	0.97
Tyne	trust	0.82	0.89	0.90	0.90	0.90	0.90	0.88
		0.71	0.84	0.90	0.73	0.76	0.52	0.76
Milford Haven	trust	0.87	0.89	0.88	0.90	0.91	0.86	0.88
		0.78	0.67	0.69	0.56	0.76	0.44	0.65
Medway	trust	0.89	0.86	0.87	0.88	0.88	0.89	0.88
		1.00	0.82	0.83	0.65	0.72	0.69	0.78
Clyde	trust	0.86	0.87	0.87	0.86	0.87	0.91	0.87
		0.85	0.81	0.87	0.51	0.65	0.67	0.71
Felixstowe	private	0.81	0.83	0.89	0.90	0.88	0.87	0.87
		1.00	0.79	0.85	0.93	0.61	1.00	0.85
Liverpool	private	0.84	0.85	0.86	0.87	0.86	0.89	0.86
		0.95	0.82	0.76	0.73	0.77	1.00	0.83
Bristol	municipal	0.71	0.77	0.76	0.77	0.74	0.76	0.75
		0.57	0.64	0.64	0.58	0.49	0.40	0.55
Manchester	private	0.72	0.81	0.82	0.74	0.60	0.68	0.72
		0.61	0.71	0.73	0.68	1.00	0.20	0.59

Note:

[1] Geometric average.

[2] The figures in the first row are parametric measure of PTE, i.e. EXP(-U) given the inefficiency given estimates of inefficiency term U.

[3] The figures in the second row are non-parametric measure of output-based PTE.

By parametric measure the five most efficient ports with the 6-year average PTE $\geqslant 90\%$ are ABP, Forth, Tees & Hartlepool, Dover and London (apart from ABP the remaining four are trust ports), and the two least efficient ports with the 6-year average PTE $\leqslant 80\%$ in terms of the average PTE scores are Manchester and Bristol, which are in turn private and municipal port. The ranking by non-parametric measure is different. The three most efficient ports with average PTE $\geqslant 90\%$ are London, Forth and Dover and the six least efficient ports with average PTE $\leqslant 80\%$ are Bristol, Manchester, Milford Haven, Clyde, Tyne and Medway.

In both cases the private ports Felixstowe and Liverpool are regarded as second class and Manchester is counted as one of the least efficient ones. One may argue that private ports on the whole perform better than the only municipal port, Bristol, which is among the least efficient ones in both cases. But trust ports are as efficient as private ports. There is no clear-cut pattern when one compares the performance between private ports and trust ports.

To investigate the comparative efficiency of alternative forms of port ownership on the basis of the whole sample evidence, the average values of PTE for each ownership group in terms of alternative measures are computed and presented in Table 6.1-1. Figures in parentheses are the standard errors of estimated efficiency. By parametric measures trust ports seem to be the most efficient ones, followed by private ports, municipal ports and a national port. By non-parametric measures, private ports seem to perform better that trust ports, municipal ports and a national port in turn. In all cases the national port (British Waterays Board) appears to be the least efficient. However, the difference between private and other public ports (especially trust ports) is small. Do these figures produce a real difference between public and private ports or indicate merely a matter of sample variations? In what follows the implications of port ownership structures for efficiency is considered in an Newman-Pearson hypothesis testing framework. We ignore the one national port since this sample is too small for inference. Thus trust ports and municipal ports are compared with private ports.

The hypotheses are set up as follows:

$$H_0: PTE_1 = PTE_2$$

$$H_1: PTE_1 < PTE_2$$

where PTE_1 is the average PTE of trust or municipal ports and PTE_2 is the average PTE of private ports. Thus the null hypothesis that there is no significant efficiency difference between trust (or municipal ports) is tested against the alternative hypothesis that private ports are more efficient than trust ports (or municipal ports).

Table 6.1-2 Average PTE of Alternative Forms of Port Ownership

Port Ownership	Parametric Measure		Non-Parametric Measure	
	[1]	[2]	[3]	[4]
Private Ports	0.799	0.850	0.751	0.720
	(0.073)	(0.070)	(0.255)	(0.231)
Trust Ports	0.805	0.870	0.700	0.695
	(0.083)	(0.066)	(0.278)	(0.268)
Municipal Ports	0.731	0.798	0.664	0.620
	(0.057)	(0.061)	(0.160)	(0.156)
National Port	0.581	0.530	0.345	0.299
	(0.030)	(0.055)	(0.187)	(0.169)

Notes:

[1] under the half-normal assumption.

[2] under the exponential assumption.

[3] input-based.

[4] output-based.

The test statistic is

$$(6.5\text{-}1) \qquad Z = \frac{(\overline{PTE}_1 - \overline{PTE}_2) - (PTE_1 - PTE_2)}{(s_1{}^2/n_1 + s_2{}^2/n_1)^{1/2}}$$

which is normally distributed with mean zero and variance one. Here s_1 and s_2 are the corresponding standard errors. The values of this statistic for alternative measures are presented in Table 6.1-3.

Table 6.1-3 The Values of Statistic for Testing the Efficiency Differentials

	Trust vs. Private ports	Municipal vs. Private Ports
[1]	0.433	-3.258
[2]	1.574	-2.406
[3]	-1.132	-1.551
[4]	-0.602	-1.893

Notes:
[1] in terms of parametric measure under the half-normal assumption.
[2] in terms of parametric measure under the exponential distribution.
[3] input-based non-parametric measure.
[4] output-based non-parametric measure.

At the 5% significance level the critical value is –1.65. The test statistic is well within the acceptance region for all measures when we compare trust ports with private ports. Thus there does not appear to be a significant efficiency difference between trust and private ports. When we compare municipal ports with private ports, the test statistic falls into the rejection region for three out of four efficiency measures. The sample evidence thus favours the alternative hypothesis, namely, private ports are more efficient than municipal ports.

Labour scheme

It has been argued that the productive efficiency of UK ports has been hampered by the National Dock Labour Scheme, which has been the most important restrictive practice in the industry and was abolished in the summer of 1989. The Dock Labour Scheme was introduced in 1947 by the post-war Labour Government as a direct response to the chaotic employment conditions which existed in the docks prior to the war. The scheme was significantly strenthened by the then Labour Government in 1967. Under the scheme casual employment was prohibited and the National Dock Labour Board that was to be responsible for the number of dock workers employed and for the definition of dock works. The Scheme covered a large number of commercially important ports which shared 68% of the volume of trade through UK ports. The Scheme was an alleged cause of overmanning and of an ageing labour forces in scheme ports. According to the National Port Employers Association, in 1986 the average surplus of labour in each Scheme port was estimated to be 12% of the total work force; the average age of a registered docker had risen to 47 because, with declining labour requirements, new recruitment had been unusual. Moreover the Scheme was blamed for the disproportionate power of the dockers' trade unions, as trade unions and employers had 50-50 representation on 20 local boards. Thus the Scheme was said to impose a substantial labour cost burden on port employers, besides hampering productivity and encouraging inefficiency. Frequently cited evidence of this is the decline of scheme ports on the east coast and the contrasting prosperity of non-scheme Felixstowe. The demise of the labour scheme was expected to restore management's freedom and incentive to manage by breaking the dockers' statutory monopoly on dockwork; to bring about a remarkable change in the attitudes of the workforce and industrial relations at the port; and to facilitate the adoption of new working practice and handling techniques. The primary benefit of abolition was reckoned to be massive cost reductions and productivity improvement. At least this is a view widely shared in official circles and in the media.

However, there has been very little concrete evidence of this to date (Turnbull, 1991). According to a report in the Employment Gazette (1990) the productivity improvement was as high as 100%. As Turnbull has pointed out, this claim was based on examples of improved cargo handling performance taken from just three ports in one day. And in these ports new working arrangements have extended effective working hours both in respect of gross hours worked and effective utilisation of labour during those hours. It is thus impossible to determine whether ships are turned round more quickly because of improvement in productivity or longer working hours.

We can draw inferences about the effects on productivity of the abolition of the scheme by comparing the relative performance of non-scheme ports with scheme ports. The influence of the Labour Scheme on efficiency is investigated by testing the average efficiency differnce between scheme and non-scheme ports in a smae way as we did for ownership. The average PTE and the corresponding standard errors for both scheme and non-scheme ports are calculated and presented in Table 6.1-4. The null hypothesis is that there is no efficiency difference between scheme and non-scheme ports and the alternative hypothesis is that non-scheme ports are more efficient than scheme ports. The values of the test-statistic are given in the last column. Surprisingly these are all within the acceptance region at the 5% level. Thus we would not reject the null hypothesis of no efficiency difference between scheme and non-scheme ports. The sample evidence does not seem to support the claim that the abolition of the scheme has reshaped the attitudes of the workforce and industrial relations at the ports and facilitated the introduction of new handling techniques.

In addition, as we discovered in chapters 3 and 4, the results of both deterministic and stochastic analysis confirm that the structure of British port production technology is free from congestion in labour as might be expected by the Scheme.

Table 6.1-4 Average PTE for Scheme and Non-Scheme Ports

	Scheme Ports	Non-Scheme Ports	Difference[5]
[1]	0.800	0.784	1.129
	(0.080)	(0.099)	
[2]	0.857	0.834	1.542
	(0.069)	(0.110)	
[3]	0.692	0.697	0.136
	(0.249)	(0.296)	
[4]	0.654	0.704	-1.379
	(0.232)	(0.301)	

[1] under the half-normal assumption.
[2] under the exponential assumption.
[3] input-based.
[4] output-based.
[5] The value for the sample mean difference tests. See Eq(6.1-1).

Turnbull argued that the major institutional changes in British ports have done little to transform the adversarial nature of labour relations. As he explained 'coerced compliance' rather than 'co-operative commitment' still characterises the labour relations of many ports, as shown by the ability and willingness of dockers to manipulate the new 'flexibility agreements' to their advantage. An example of this at one West Coast port cited by Turnbull is that dockers quickly adapted to a new pay system in order to make it work for them. The old practice was that trimmers were allocated to bulk vessels from the commencement of work. Under the new pay system trimmers were now allocated only when an initial need arises, and they remain until the hold completes. Once they are allocated the gang earns a higher bonus rate to encourage more rapid completion of the cargo at the higher manning level. The 'trick' now, however, is for the crane drivers to 'free grab' as much cargo from the centre of the hold as quickly as possible to ensure the early allocation of the trimmers and the higher bonus pay. In consequence, although labour productivity has increased, unit labour costs have increased as well.

We now turn to technological factors of interest. The co-existence of different structures of production technology is the cause of technical inefficiency. Substantial inter-port inefficiencies in the industry tell us the possible extent of improvement from the average technologies to the best-practice technology. It should then be useful for both public and private policy reasons if the best-practice technology can be characterised. In this aspect three distinct hypotheses can be tested: that a large port technology is more efficient than small port technology; that a technology of high capital intensity is more efficient than technology of low capital intensity; that ports concentrating on specific modes and commodities are more efficient than ports providing comprehensive facilities to handle a variety of cargoes.

The coefficient of simple correlation between PTE (parametric measure based on exponential distribution), turnover Q, net-book value of fixed assets C, staff costs L, capital/labour ratio C/L, labour productivity and capital productivity are shown in Table 6.1-3. We may use L as a proxy measure of port size and C/L as a measure of capital intensity. Shown in parentheses are values of t-test statistic of the significance of correlation. This follows a t-distribution with n-2 degrees of freedom. A two-tail test was chosen because correlation can be either positive or negative. For n=188 (observations during 1983-1990), the critical value of the t distribution for a two-tail test with 186 degrees of freedom at the 5% significance level is 1.96.

Port size

Britain is endowed with an unusually large number of small ports. For instance, apart from 8 mainstream UK container ports handing in excess of 100,000 TEU per annum, there are 25 small ports, mostly located along the east coast and with container throughput varying from just over a thousand TEU to 80,000 TEU.

These small ports handle 20 % of UK container traffic. Despite the philosophy of concentration of port traffic in fewer and bigger ports, many small ports in the UK continue to survive and to show a modest increase in throughput in the face of severe port competition.

One of the main reasons why small ports remain viable is that the customers of these small ports tend to be relatively small scale short-sea operators deploying small-sized vessels, for which the facilities available in small ports are ideally suited. Also small operators in small ports are big fish in a small pond and are offered personal and flexible services. Small ports can give quick decisions and can give their personal attention to each customer. Furthermore the increasing trend for deep sea carriers to call at fewer ports and to feeder cargo to/from other destinations is a further boost to the small ports.

Table 6.1-5 Technological Factors and Purely Productive Efficiency

	PTE[1]	Q	C	L	CL	CP	LP
Q	0.196	1.000					
	(2.72)[2]						
C	-0.163	0.836	1.000				
	(-2.24)	(20.72)					
L	0.044	0.959	0.869	1.000			
	(0.60)	(46.02)	(26.05)				
CL	-0.043	-0.268	-0.154	-0.298	1.000		
	(0.60)	(-3.78)	(-2.12)	(-4.24)			
CP	0.115	-0.047	-0.124	-0.047	-0.187	1.000	
	(1.57)	(-0.63)	(-1.70)	(-0.63)	(-2.59)		
LP	0.329	-0.225	-0.273	-0.333	0.880	0.248	1.000
	(4.74)	(-3.14)	(-3.85)	(-4.80)	(25.20)	(3.58)	

Notes:

[1] PTE is a parametric measure based on the exponential distribution;

[2] The figures in parentheses are t-ratios of associated simple correlation coefficients; $t=r\sqrt{((n-2)/(1-r^2))}$, which follows a t-distribution with d.f (n-2).

Small ports thus remain viable because of service differentiation. The question is whether small port technology requires higher costs. Since modern port technology is highly capital intensive, there is a belief that considerable efficiency can be gained from economies of scale. If this is true, there will be a strong case for mergers of small ports. The implication of this for public policy is a dilemma: how to enjoy the cost benefits of large port production without suffering monopolistic behaviour. But using L as a proxy measure of port size, we found that the correlation between PTE and port size is close to zero and highly insignificant. We thus discover no evidence to support the proposition that large port technology is more efficient than small port technology. This result is consistent with our descriptive evidence earlier that the level of concentration in the industry has remained almost unchanged over the last 20 years or so. Both seem to imply that the port technology does not exhibit the expected substantial economies of scale.

While cost-reducing gains could be realised with an increase in port size, there are also several reasons why at the same time efficiency may be expected to decline. First, because of the small number of employees, better staff relations usually obtain, with the result that any grievances are usually dealt with directly without the need for posturing or escalation to a national level. Second, an increase in port size may lead to a reduced speed and flexibility of decision-making and increased difficulty of and cost of coordination. Third, the superiority of a large-scale operation usually depends on full or nearly-full use of port capacity. When throughput falls, the big port is left with costs, incurred in order to handle larger cargo volume, which it cannot reduce at will. Small ports may be less capitalised, having a higher variable/fixed cost ratio and can therefore adjust their costs to current throughput more flexibly. This point is particularly relevant since variation in demand is a typical feature of the port industry. Economies of scale depend on maintenance of large ouptut. In the face of demand fluctuations big ports cannot consistently achieve economies of scale. Therefore the effects of port size are multiple and complex. The net effect can go either way.

Capital intensity

Without doubt the dramatic increase in the productivity of cargo handling since World War Two has been attributed to the mechanisation of port operation. In 1965 UK port labour handled 1.6 tons of cargo per man hour and this figure in 1988 had increased to 8.5 tons per man hour. In the port industry, which used to be notoriously labour intensive, the manning level has been reduced so that most workers are now equipment operators. Still commercial pressure to reduce manning and improve efficiency remains high. As the present ageing UK dock labour force retires the ports will take on younger port employees who have different attitudes and better education, but who will expect high wages and good conditions. Under commercial pressure a trend towards ports "without people" has started with port automation. Important automation schemes include operation automation in container terminals (e.g. the automation of stackyard operation, the automation of horizontal movement to/from the stackyard) and in dry bulk terminals (e.g. self-discharging vessels in the dredged aggregates trade combined with a modern conveyor system), and computation and electronic data handling of port traffic. The question from the efficiency point of view is whether the best-practice technology can be identified with high capital intensity. The answer to this question is important for policies of R&D and technical progress.

The coefficient of correlation between CL and PTE, as revealed in Table 6.1-3, rejects any significant association between the best-practice technology and high capital intensity. The substitution of capital for labour at a given technical level is not without limit. The introduction of additional mechanical equipment or automation scheme may result in an increase in the labour productivity and a decrease in labour cost on the one hand, but involves considerably more capital cost. Moreover, as stated above, ports which are highly capitalised tend to be inflexible in adapting to fluctuating demand and thus have lower capacity utilisation and higher unit costs. Thus it is not suprising that ports with higher capital intensity are not necessarily more efficient than ports with lower capital intensity.

Modes of operation/Types of cargo

We could not find any evidence, either, to support the hypothesis that specialised ports are more efficient than ports providing comprehensive facilities and handling a variety of cargoes. Table 6.1-4 indicates the PTE rankings of 28 British ports in terms of their 6-year average PTE. The main types of cargo handled in each port are also described. Large, traditional ports providing comprehensive facilities developed over the years to handle most cargoes – container, bulk, ro-ro and general cargo – are among the efficient ones, e.g. London, Tees & Hartlepool and Forth, as well as among the inefficient ones such as Manchester and Bristol. This is also the case for ports which specialise in specific modes or commodities – container and ro-ro. There is no clear pattern as to which type of port is more efficient than another.

Geographical pattern

However, we have discovered a geographical pattern for PTE. If one looks at both the most and the least efficient ports in Table 6.1-4 on a map, it is immdiately clear that, by and large, efficient ports such Harwich Dock, Aberdeen, Forth, Tees & Hartlepool, London and Dover are concentrated on the East Coast, while the inefficient ports such as Bristol, Manchester and Ardrossan are on the West Coast. This probably reflects the changing pattern of the UK's international trade. Amongst the larger ports in this country those situated in the Channel area handle mainly EEC trade while those on the West Coast tend to handle a large volume of deep sea trade. The major exception to this is Felixstowe which handles both short sea and deep sea trade. Since the mid 1960s, the relative importance of short sea trade with EEC countries has increased whereas the significance of links with the UK's traditional trade partners has declined. Unlike other industries, ports are unable to relocate to meet the geographical change of markets. In consequence, the port business has become prosperous on the South and East Coasts and diminished on the West Coast. Another possible reason for the geographical pattern of efficiency is the intense inter-port competition in this area (e.g. for container and Ro-ro traffic) which can act as a spur to port efficiency.

Table 6.1-6 PTE Rankings of British Ports 1983-1990

Ports	Type of Cargo
1.Great Yarmouth PTE-0.95	Offshore supply, Ro-Ro, ferry, liquid, bulk
2.Harwich Harbour PTE-0.94	Navigation, conservancy, pilotage
3.Aberdeen PTE-0.93	Passenger, marine support for offshore oil, bulk, Ro-Ro
4.ABP PTE-0.91	Container, ro-ro, general, dry and liquid bulk
4.Forth PTE-0.91	Oil, petro-chemicals, unitised general and dry bulk
4.Tees & Hartlepool PTE-0.91	Oil, chemical, steel, bulk, Ro-Ro, container, and general cargo
5.Dover PTE-0.90	Ferry port. Ro-Ro, hover-craft and jetfoil services
5.London PTE-0.90	Container, Ro-Ro, general cargo, dry and liquid bulk, passenger
6.Dundee Firth PTE-0.89	Bulk and general cargo, container, Ro-Ro
6.Harwich Dock PTE-0.89	Container, general, forest products, Ro-Ro
7.Tyne PTE-0.88	Timber, forest products, ferry services, containers, general bulk
7.Medway PTE-0.88	Container, Ro-Ro, forest products, fruit, meat
8.Lerwick PTE-0.87	General, Ro-Ro, ferries, cruise liners

Table 6.1-6 (continued) PTE Rankings of British Ports 1983-90

Ports	Type of Cargo
8.Clyde PTE=0.87	Container, iron ore, coal, grain and other dry and liquid bulk
8.Felixstowe PTE=0.87	Container port. Ro-Ro, general, bulk
8.Ramsgate PTE=0.87	General cargo, timber, car and oil port
9.Liverpool PTE=0.86	Comprehensive cargo handling facilities for containers, break bulk, dry and liquid bulk
9.Milford Haven PTE=0.86	Oil terminal. Ro-Ro, general cargo
10.Boston PTE=0.85	Container, general, timber, steel bunkers
11.Blyth PTE=0.83	A general cargo, Ro-Ro-Sto-Ro port specialising in forest products and bulk commodities
11.Poole PTE=0.83	Recreational facilities, Ro-Ro, general, passenger
12.Ipswich PTE=0.82	Container terminals, general cargo, bulk liquids grain and other bulk solid cargoes
13.Shoreham PTE=0.81	General cargo, timber, conventional bulk
14.Bristol PTE=0.75	Wet and dry bulk, forest products, Ro-Ro, general
15.Cromarty Firth PTE=0.74	General and bulk cargo, oil and oil field support base
15.Manchester PTE=0.74	All bulk liquid, dry bulks, containers, heavy individual loads, Lo-Lo and Ro-Ro
16.Ardrossan PTE=0.71	Ro-Ro, container, unit loads, break-bulk
17.BWB PTE=0.56	River ports

6.2 Determinants of Scale Efficiency

Scale inefficiency is another important way that British port producers depart from overall productive inefficiency. During 1983-1990 British ports were about 82% scale efficient in the half-normal case and 80% scale efficient in the exponential case. Relative to the deterministic frontier the value was lower.

Scale inefficiency occurs because of the failure to operate at the most productive scale size (i.e. the maximum productivity per unit of inputs) for a given input and output mix. The notion of scale referred to here is related to returns to scale rather than economies of scale. It is useful to distinguish between the problem of determining the most productive scale size for a particular input and output mix, and the problem of determining the minimum cost of inputs on the basis of their relative prices (Banker, 1984). For each input and output mix there is a corresponding most productive scale size, while the overall optimal scale size depends on prevailing prices as well. Thus the optimal scale here is a local rather than a global one. The most productive scale size corresponds to the long run competitive equilibrium only when the factor ratio is optimal given factor prices.

Unlike purely productive inefficiency and congestive inefficiency, scale inefficiency is not necessarily an error on the part of producers (Fare, *et al.*, 1985). As evidence of this, Table 6.2-1 shows that no correlation was found between scale efficiency and purely productive efficiency, which is the form of private inefficiency in the industry. Ports which are productive inefficient need not be scale inefficient. The converse is true as well. Nevertheless, scale inefficiency is undesirable from a social point of view.

Given that scale inefficiency is not an error from the private point of view, organisational factors such as ownership and the labour scheme are not relevant causes. Our attention will thus be focused on technological factors only. The coefficients of correlation between the parametric measure of scale efficiency (SE) and the proxy measures of port size (L), capital intensity (C/L), capital productivity (CP) and labour productivity (LP) are given in Table 6.2-1. For comparison the corresponding coefficients of correlation between the parametric measure of PTE and the proxy measures of technological factors are shown in the same table as well. Again the figures in parentheses are t-ratios of corresponding simple correlation coefficients. For a simple correlation to be significant at 5% significance level, the test statistics must exceed 1.96 (a two-tail test).

Table 6.2-1 Technological Factors and Scale Efficiency

	SE[1]	PTE
SE	1.000	0.120
		(1.64)
PTE	0.120	1.000
	(1.64)[2]	
Q	-0.270	0.196
	(-3.81)	(2.72)
C	-0.501	-0.163
	(-7.87)	(-2.24)
L	-0.212	0.044
	(-2.95)	(0.60)
CL	-0.655	-0.043
	(-11.79)	(-0.60)
CP	0.320	0.115
	(4.59)	(1.57)
LP	0.485	0.329
	(7.00)	(4.74)

Notes:

[1] SE is a parametric measure under the exponential assumption;

[2] The numbers in parentheses are test statistics of the significance of correlation, which follows a t distribution with (n-2) degrees of freedom.

As suggested in Table 6.2-1, SE is negatively related to the level of production, the usage of labour input and capital input in particular, but the correlation is not very strong. While there is a lack of correlation between capital intensity and purely productive efficiency, the correlation between capital intensity and scale efficiency is negative and significant.

Our parametric estimates in chapter 4 suggested a strong association between scale efficiency and scale elasticity. It can be seen in Fig 4.4-3 that the closer the value of scale elasticity is to unity, the higher the scale efficiency. The estimates of scale elasticity for each port revealed in Table A4.4-3 and A4.4-4 make it clear whether scale inefficiency for each observation was due to increasing returns to scale or decreasing returns to scale. For most ports, especially large ports, scale inefficiency was attributed to decreasing returns to scale. In other words most British ports operate on a scale larger than the most productive scale size given their factor ratios. We can also identify the sources of scale inefficiency for each port in non-parametric models by comparing the value for weakly productive efficiency WTE and the value for weakly productive efficiency on the star-input correspondence WTE* (FCL, 1988). If there is input scale inefficiency, i.e. $ISE \neq 1$, then it is caused by increasing returns to scale if and only if $IWTE < IWTE^*$, and it is caused by decreasing returns to scale, if and only if $IWTE = IWTE^*$.

The values for IWTE and IWTE* for British ports during 1985-1990 can be found in the tables of Appendix 3.3. They are summarised in Table 6.2-1 and the source of scale inefficiencies for each observation is identified in the same table. One striking result is that the cause of scale inefficiency tends to be decreasing returns to scale for large ports and increasing returns to scale for small ports. In other words large ports tend to operate above their most productive scale sizes while small ports tend to operate below their most productive scale sizes.

Table 6.2-2 Source of Scale Inefficiency for UK Ports 1985-90

Ports	Scale Efficiency/Sources			
	1985	1988	1989	1990
ABP		0.132 DRS	0.418 DRS	
Bristol	0.589 DRS	0.156 DRS	0.390 DRS	0.481 DRS
Clyde	0.519 DRS	0.172 DRS	0.589 DRS	0.572 DRS
Dover	0.542 DRS	0.135 DRS	0.243 DRS	0.449 DRS
Felixstowe	0.430 DRS	0.137 DRS	0.423 DRS	0.259 DRS
Forth	0.574 DRS	0.158 DRS	0.429 DRS	
London	0.446 DRS	0.137 DRS	0.385 DRS	1.000 CRS
Manchester	0.546 DRS	0.150 DRS	0.216 DRS	0.863 DRS
Medway	1.000 CRS	0.162 DRS	0.444 DRS	0.423 DRS
Mersey	0.139 DRS	0.415 DRS	1.000 CRS	
Milford Haven	0.976 DRS	0.381 DRS	0.473 DRS	0.593 DRS
Tees & Hartlepool	0.532 DRS	0.148 DRS	0.435 DRS	0.418 DRS
Tyne	0.636 DRS	0.178 DRS	0.445 DRS	0.556 DRS
Aberdeen	0.827 DRS	0.225 DRS		
Ardrossan	0.865 DRS	0.988 DRS	0.387 DRS	0.993 IRS
Blyth	0.608 DRS	0.232 DRS	0.501 DRS	0.617 DRS
Boston	0.771 DRS	0.272 DRS	0.738 DRS	
Cromarty Firth	0.766 DRS	0.741 IRS	0.899 DRS	0.934 IRS
Dundee Firth		0.370 DRS	0.436 DRS	0.590 DRS
Great Yarmouth	1.000 CRS	0.672 DRS		
Harwich Harbour	1.000 CRS	0.342 DRS	0.360 DRS	0.563 DRS
Ipswich	0.527 DRS	0.177 DRS	0.413 DRS	0.451 DRS
Lerwick	1.000 CRS	0.384 DRS	0.423 DRS	0.919 IRS
Poole	0.797 DRS	0.245 DRS	0.469 DRS	0.601 DRS
Shoreham	0.996 IRS	0.700 DRS	0.548 DRS	0.743 DRS
Cowes		0.147 DRS	0.665 IRS	0.559 IRS
Dart		0.217 DRS	0.601 IRS	
Falmouth Habour		0.901 IRS	0.863 IRS	
Fraserburgh		0.651 IRS	0.518 IRS	
Harwich Dock	1.000 CRS	1.000 CRS		
King's Lynn		0.340 IRS	0.992 IRS	0.795 IRS
Lancaster		0.983 IRS		
Montrose	0.780 IRS	0.976 IRS	0.795 IRS	
Milford Dock	0.987			
Newlyn	0.243 IRS			
Padstow	0.233 DRS	1.000 CRS		
Peterhead Bay	0.503 IRS	1.000 CRS	1.000 CRS	
Peterhead Harbour		0.987 IRS	0.848 IRS	
Ramsgate	1.000 CRS	0.362 DRS	0.329 DRS	0.891 DRS
Stornoway		0.362 IRS	0.795 IRS	0.586 IRS
Sutton	1.000 CRS	0.471 IRS	0.553 IRS	0.497 IRS
Ullapool		0.336 IRS	0.373 IRS	
Whitehaven		0.436 IRS	0.967 IRS	0.791 IRS
Yarmouth(IOW)		0.316 IRS		

Notes:

DRS decreasing returns to scale; IRS increasing returns to scale; CRS constant returns to scale; SE is non-parametric and input-based.

6.3 Determinants of Dynamic Efficiency

Technical progress offers both an opportunity and a challenge to individual ports. It is an opportunity because the shifting production frontier expands the production possibility set, in which more output is obtainable with a given set of inputs if the best-practice technology is applied. It is a challenge because the failure to adopt the best-practice technology may place the port and terminal operators at a disadvantageous position in competitive situations. In what follows we examine the influences of port ownership, labour scheme and technological factors on dynamic efficiency.

As in their static productive performance, the dynamic performance of British ports also differs widely. This can be seen in Fig 5.3-5 which shows δTFP of British ports during 1983-1990 excluding exogenous influences: the annual growth rate of total factor productivity for individual observations varied from -22.5% to 27.5%. The distribution of δTFP is symmetric. Because the growth rate of total factor productivity can be either positive or negative, we translate δTFP into the rate of technical progress on the frontier and the rate of efficiency improvement. Given that the structure of port production technology in Britain remained unchanged during the period 1983-1990, efficiency gains (positive or negative) over time were thus mainly attributed to changes in productive efficiency relative to efficiency frontiers of the industry.

Port ownership and labour scheme

Ports which are conducive to technological development must possess two factors. One is innovation incentive. The other is financial capacity. As far as innovation incentive is concerned, once more, market structure is more important than ownership *per se*. Ports in a monopoly position, whether private or public, tend to be lax and inefficient and fail to grasp opportunities of technical progress as compared with ports in a more competitive environment. In Britain port markets are mixed where public ports are in competition with private ports. There is no reason to believe that public ports are less keen than private ports on technological development. One may even argue that publicly owned ports which often take throughput maximisation as one of their management objectives tend to show more willingness to invest for port expansion and upgrading, whereas private port management may be reluctant to sacrifice short term profits for long term development under the pressure to make profits for the benefit of their shareholders. As far as financial capacity is concerned, private ports are in a better position to finance technical progress, as company status facilitates wide access to external capital than currently available to public ports. Municipal ports are especially at a disadvantage because of under-funding of local authorities. Actually one of the objectives of the second stage of port privatisation relates to port development. But the difficult situation of public ports in Britain is attributed more to the free market policy of government than to their ownership status. In continental Europe, by contrast, the municipal ownership status of ports, such as Rotterdam, Antwerp, Hamburg, Bremen, has not become an obstacle to port development. Rather it has been a legitimate reason for financial assistance from government in major infrastructure, which has been important to enable these ports to attain a high level of technical sophistication. While port subsidy is not justified on allocative efficiency grounds, this example seems to indicate that there is no necessary defect in the mechanism of public control as far as technological advance is concerned.

Again we use dummy variables to investigate the influence of port ownership and the labour scheme as in Eq(6.1-1) on the growth rate of total factor productivity δTFP and the rate of productive efficiency improvement ΔPTE. Recall that the estimates for ρ_1 represent the sample mean of the relevant dependent variable (δTFP, ΔPTE and δF as appropriate) for private and non-scheme ports, and the estimates for ρ_2, ρ_3, ρ_4 and ρ_5 represent the differential effects of trust ports, municipal ports, national ports and scheme ports on the dependent variable as compared with private and non-scheme ports.

Table 6.3-1 reports the results of the dummy variable analysis. We found that the estimated ρ_1 associated with δF, ΔU and δTFP are all close to zero and insignificant. This reveals that there was little total factor productivity growth achieved by private and non-scheme ports on average because neither did the best-practice technology shift nor did they improve productive efficiency significantly. We also found that estimated ρ_2, ρ_3 and ρ_4 associated with δTFP, ΔU and δF are also insignificant. This implies that there was no significant difference in dynamic efficiency between public ports of all forms and private ports whether in terms of δF or ΔPTE or in consequence of δTFP. The conclusion is the same when comparing scheme and non-scheme ports. Therefore British ports on average achieved little productivity growth during this period regardless of ownership, though improvement or deterioration in total factor productivity was significant for individual ports. In other words differences in dynamic efficiency can hardly be explained by differences in ownership or by the labour scheme.

The second part of Table 6.3-1 shows the influence of port ownership and labour scheme on purely productive efficiency PTE as measured in terms of the stochastic frontier of each year during 1983-1990 (the dynamic translog model estimated in chapter 5) instead of the unique stochastic frontier of this period (the static translog model estimated in chapter 4). The result of this dummy variable analysis is almost identical to that shown in Table 6.1-2. Private ports performed slightly better than municipal ports and much better than the national port. But there was no significant difference in productive performance between private and trust ports, nor between scheme and non-scheme ports.

As a final note, the values of the F-test statistic for the joint significance suggest that, while ownership explains static efficiency differentials to some extent, it does not explain dynamic efficiency differentials at all.

Table 6.3-1 The Influence of Port Ownership on Dynamic Efficiency

	ρ_1	ρ_2	ρ_3	ρ_4	ρ_5	
δTFP	0.018	0.008	0.005	-0.021	-0.013	
	(0.011)	(0.012)	(0.022)	(0.030)	(0.010)	[1]
		F(5,155)=0.603 [2]				
ΔPTE	0.003	0.012	0.006	-0.019	-0.018	
	(0.011)	(0.012)	(0.022)	(0.030	(0.010)	[1]
		F(5,183)=1.013				
δF	0.016	-0.004	-0.001	-0.001	0.004	
	(0.011)	(0.003)	(0.003)	(0.004)	(0.001)	[1]
		F(5,183)=4.616				
PTE(half-normal)	0.794	0.002	-0.080	-0.221	0.011	
	(0.014)	(0.015)	(0.028)	(0.039)	(0.013)	[1]
		F(5,183)=132.68				
PTE(exponential)	0.848	0.012	-0.060	-0.319	0.006	
	(0.012)	(0.013)	(0.023)	(0.032)	(0.010)	[1]
		F(5,183)=136.56				

Notes:

[1] Standard errors are in the parentheses below the parameters.

[2] F-test statistic is for the joint significance of all variables in the equation concerned.

Technological Factors

Table 6.3-2 reports the results of correlation analysis on dynamic efficiency and technological factors. The figures in the table are the coefficients of correlation and the figures in the parentheses are the values of t-statistic.

δTFP has a positive correlation with ΔPTE as high as 99.1% while it has no correlation with δF. This confirms that the main component of δTFP is ΔPTE. But it is difficult to characterise the improvement in productive efficiency, since the coefficients of correlation between ΔPTE and variables such as Q, C, L and CL are insignificant. Nevertheless, there is some degree of positive correlation between PTE and δPTE. This means that ports which are efficient in the static sense tend to be efficient in the dynamic sense. But the correlation is very weak.

Table 6.3-2 Technological Factors and Dynamic Efficiency

	δTFP	ΔPTE	δF	PTE
ΔPTE	0.991	1.000		
	(93.90)			
δF	-0.021	0.156	1.000	
	(-0.264)	(1.985)		
PTE	0.234	0.227	0.037	1.000
	(3.025)	(2.93)	(0.465)	
Q	0.080	0.061	0.135	0.211
	(1.009)	(0.768)	(1.71)	(2.713)
C	-0.023	-0.014	-0.061	0.179
	(-0.289)	(-0.176)	(-0.768)	(2.287)
L	0.026	0.003	0.169	0.035
	(0.327)	(0.038)	(2.129)	(0.440)
CL	0.006	0.113	-0.790	-0.0182
	(0.075)	(-1.411)	(-16.20)	(-0.229)
CP	0.015	-0.073	0.648	0.083
	(0.189)	(0.915)	(10.69)	(-1.047)
LP	0.111	0.200	-0.674	0.353
	(1.404)	(2.566)	(-11.469)	(4.743)

Note: The numbers in parentheses are the test statistic of the significance of correlation, which follows a t distribution with (n-2) degrees of freedom.

6.4 Concluding Remarks

6.4.1 Summary Of The Study

Purposes and Methodologies

This study concerns the productive efficiency impact of ownership in the British port transport industry. Unlike previous studies on whether public ownership leads to better or worse performance, which relied on observable and possibly biased variables in measuring productive efficiency (for survey on the literature of performance studies see Vickers and Yarrow (1989, pp.39–43)), we have taken efficiency measures defined and constructed within the rigorous framework of frontier function theory. The notion of a frontier is consistent with the underlying economic theory of optimising behaviour. Deviations from a frontier have a natural interpretation as a measure of the efficiency with which firms pursue their technical or behavioural goals. Information about the relative efficiency of firms and about the structure of the frontier has many public and private policy implications.

The frontier models adopted and developed in this study allow us to delineate the various ways in which a firm might fail to achieve its technical or behavioural goals. Relative to a production frontier in a given period of time, deterministic or stochastic, the possible reasons for inefficiency are classified into purely productive inefficiency (in the form of X–inefficiency and/or technical inefficiency), congestive inefficiency and scale inefficiency. But the efficiency defined in the frontier models need not be restricted to a static concept. Measures of the dynamic efficiency or progressiveness of a firm can also be defined and constructed relative to an ever–shifting production frontier. Efficiency gains over time can be interpreted in terms of shifts of the frontier and movements towards/off the frontier.

Two competing paradigms for constructing frontiers have been adopted. One uses mathematical programming techniques, the other employs econometric techniques. Both techniques reveal that efficiency levels differ from port to port, but the efficiency differential suggested by the mathematical programming techniques is wider than by the econometric techniques. While the stochastic models distinguish between exogenous influences and efficiency errors, the deterministic models make no allowance for this. The variance of statistical noise was estimated to be as high as 52% to 55% of the total disturbance. Given a well-specified structure for the parametric technology, we believe that the stochastic measures were closer than the deterministic measures to the true extent of efficiency or inefficiency.

Estimated Efficiencies and the Best-practice Technology

Although efficiency estimates resulting from the use of these two techniques do not suggest identical rankings, both revealed the same compositions of inefficiency. The main ways that British ports departed from the production frontier in the period 1983–90 were purely productive inefficiency and scale inefficiency while congestive inefficiency was negligible.

If we use stochastic measures under the exponential assumption, which has a plausible estimated efficiency distribution on Farrell's criterion, there was an 18% potential for improvements in purely productive performance for average ports in the industry. Purely productive inefficiency is partly explained by X-inefficiency because of motivational deficiency at both worker and management level. In part it is due to difference in technical levels of ports. For an industry like ports, with long-lived facilities and highly specialised capital assets, the co-existence of different vintages of technologies at any time is unavoidable.

The scale inefficiency of average British ports was 20% because of departures from the most productive scale size. Scale inefficiency seems related to excessive use of the capital input relative to labour input. Both parametric and non-parametric measures have indicated the direction of improvements in scale efficiency by the values of scale elasticity or the nature of returns to scale. Most sample ports were found to operate on scale sizes where decreasing returns to scale prevailed (the value of scale elasticity was less than unity). The most productive scale size (a purely technological characteristics) is not necessarily the minimum cost mix of inputs and outputs (based on their relative prices). However, because of the volatility of factor prices, the purely technological characteristics may be useful for managerial decisions and policies for a longer period.

We found little evidence on congestive inefficiency as a possible result of the labour scheme. The structure of production technology in the industry is basically free from congestion.

Dynamic efficiency of British ports also exhibits variations. It appears that the development of the best-practice technology in the industry has reached a plateau and remained static over the second half of 1980s following dramatic containerisation and specialisation in the previous decades. Efficiency gains over time in the industry were thus brought about by shifts of the average technology towards the frontier technology and improvements in X-efficiency. But for most sample ports the rate of efficiency change kept altering its sign, indicating frequent movements towards as well as off the frontier. This probably reflects instability of X-efficiency.

We have attempted to characterise the best-practice technology in terms of port size, capital intensity and modes of operation. But we cannot find evidence to suggest that efficient ports are necessarily large, capital intensive and associated with one particular mode of operation.

At first sight demand would definitely be a significant factor behind efficiency, especially for ports which are vulnerable to market conditions. But in stochastic frontier models random shocks in demand are captured by the symmetric error component and hence should not affect efficiency estimates in theory. Neither should long-term changes in demand provided that the changes are evenly spread over the industry, since demand conditions affect the best-practice technology as well as the average technology. But changes in the trading patterns of the UK have been characterised by increases in short sea traffic with the Continent and a decline in deep-sea traffic with the traditional markets across the globe. In consequence efficient ports tend to be concentrated on the East Coast. The geographical pattern of efficiency is an indication of the impact of asymmetric demand on efficiency. In other words, to some extent, some ports are inefficient because they are on the wrong side of the country.

Efficiency and Ownership

Port privatisation in the last 10 years has brought three-quarters of the port industry into the private sector. There still remain 108 trust ports and a number of small municipal ports. Under the Conservative Government, which has been unsympathetic towards public ownership, it seems just a matter of time that the residual public sector of the industry will be entirely replaced by the private sector. The port privatisation programme is supposed to promote economic efficiency (mainly productive efficiency), but is there any empirical basis for believing the superior productive performance of private ports?

The finding of this study, summarised in Table 6.1-2, is not strongly supportive of this belief. As far as static efficiency is concerned, private ports do not outperform the most important form of public ports in the country: trust ports. As compared with municipal ports, private ports are only marginally more efficient. The national port, British Waterways Board (BWB), was the least efficient one. However, one should be cautious before jumping to the conclusion that the national port is the least efficient type of ownership, since BWB is the only observation of such a national port. Besides it is different because it consists of small river ports while all the other observations in the sample are seaports. The result is not very persuasive, as like is not compared with like. By the dynamic measure private ports are less efficient than trust and municipal ports, and more efficient than the national port. But the differences are statistically insignificant. Therefore the evidence does not establish the clear-cut superiority of private ownership in respect of productive efficiency. At least it can safely be concluded that public ports can be as efficient as private ports. Although efficiency estimates derived from different models arrive at different orders of maganitude, the conclusion remains unchanged regardless of efficiency measures used.

Rarely is one piece of statistical work 'decisive'; rather it is added to the body of evidence which researchers use to evaluate the worth of different economic theories. But the hypothesis that public ownership is inherently less productively efficient than private ownership has been subject to many empirical tests that have, on balance, provided no firm support to the hypothesis. Many agree that this is a weak conclusion which is based on at least one presumption that the relevant firm faces strong competition, and other forms of product and factor market failure are relatively unimportant. Since many of the comparative studies involved cases with product and factor market inefficiencies, it is hardly surprising the evidence is much less clear cut. The lack of a clear-cut pattern is explained by the lack of competition. It is believed that private enterprises outperform public enterprises in competitive conditions. The evidence provided in this study, however, presents an example that public enterprises can be as efficient as private enterprises even in competitive situations.

The result of our empirical analysis is consistent with the view touched on at the end of the theoretical analysis in chapter 2, where we offered two explanations. One is that public ownership is compatible with competition in the port sector and competition provides a spur to the efficiency of public ports as well as private ports. The other is that the possible deficiency of public monitoring as compared with private monitoring system has been largely reduced because of the decentralised and autonomous nature of public port administration.

The empirical results have cast serious doubt on whether any significant transformation in the productive efficiency of Britain's ports has been brought about by the privatisation programme. Since the act of port privatisation is unlikely to enhance competition and to improve managerial incentive structure significantly, we see few attractions of the programme in improving efficiency. It should be noted that we refer mainly to the second wave of port privatisation, i.e. the programme to privatise trust ports and municipal ports. We have no evidence about the relative performance of ABP ports as compared with BTDB ports. In theory the transfer of ownership from the national-government sector to the private sector could lead to significant changes in managerial incentive structures. Thus we do not believe that the privatisation of BTDB ports was a bad thing. However, we do not favour the second wave of port privatisation, especially the privatisation of the trust ports. The privatisation of trust ports was perceived as a means of increasing their ability to diversify activities and to invest in port-related transport operations. But under the Transport and Works Act (1992), restrictions on the right of trust ports to diversify have been removed. It is then hard to see what advantages privatisation has. As far as the future is concerned, we believe that port privatisation will be more advantageous in the long term if some ports remain in the public sector. The mixed-ownership will allow yardstick competition and a direct comparison of public and private port performance. In addition, the existence of public ports in the industry will prevent unfavourable market concentration and keep a competitive port industry.

Given that merger and acquisition is a major route of firm growth in the private sector, in the longer term port privatisation may well alter the nature of port markets by industrial concentration. Many small ports are distinctly unenthusiastic about privatisation as they tend to rely on specialist trades or a few major customers, and would be vulnerable to the market and to predatory takeover bids in the private sector. As more trust ports and municipal ports are privatised, the conditions for a merger and acquisition boom are being matured. This could create a marked effect of port privatisation on efficiency. The optimistic view is that the reduction in port numbers will improve efficiency as a result of exploiting economies of scale. The pessimistic view is that it will deteriorate both allocative and productive efficiency because of increased market power. It should be noted that the argument is only relevant when the acquiring port takes over the target port and puts the latter to other more profitable use (non-port activities). If the acquiring port does not close down the acquired port, it will increase its market dominance without reducing port numbers. In this case the economies-of-scale argument will not be persuasive. While the reduction in port numbers will definitely narrow the scope of competition and hence affect port efficiency in a negative direction, the magnitude of its positive effect will depend much upon the extent of economies of scale exhibited in both shipping and port technology. This could be a controversial issue of competition policy in the aftermath of port privatisation. (By the way, sooner or later the ABP ports could be referred to the Monopoly and Mergers Commission for investigation as their market share exceeds 25%).

Two pieces of evidence revealed in this study have cast doubt on substantial economies of scale which were expected. The first is that traffic concentration has remained fairly stable over last 20 years or so. One may argue that public ownership status has prevented market forces from realising potential economies of scale. But ship operators are free to choose ports and they have more say in deciding the pattern of traffic distribution. Although port operators can lower port charges to influence ship operators' decision, the role of port costs is limited and often unimportant. Actually the prices charged by some small ports involving short-sea container traffic were higher than by large ports. The second piece of evidence is that port size does not explain wider efficiency differentials in the industry. In other words small ports are as efficient as big ports and there has been no indication of efficiency gains from economies of scale.

So far we have only discussed costs from the port producers' and the customers' side. There is one more dimension of costs associated with traffic concentration. The Government intends to increase the use of water transport as compared with road for environmental reasons. Thus if we include in the total cost the "green cost" of traffic concentration, the case for economies of scale could be further weakened. Therefore unless there is effective competition policy intervention in the port sector, privatisation may even affect efficiency in a negative direction.

The issue on the extent of economies of scale is worth further investigation. A new line of research might be to draw inferences about scale economies in ports by using the survivor technique (Stigler, 1958). Despite the fact that the technique has been subject to criticisms, we have some reasons for believing that its application in the British port industry is appropriate.

Although productive efficiency is the focus of our empirical investigation, we have also considered efficiency related to port pricing and investment behaviour under alternative forms of ownership in a simplified model. Port privatisation may lead to an increase in port prices. But we argued that this need not imply a deterioration in allocative efficiency. Given inelastic aggregate demand for port facilities and services, the welfare loss of monopoly pricing tends to be negligible as far as resource allocation between the industry and other sectors is concerned. It is shown that the welfare loss of monopoly pricing is also likely to be small as far as resource allocation (traffic distribution) between ports is concerned, provided that ports have uniform pricing objectives. Thus traffic distribution may be closer to the optimal pattern in a single-ownership port system than in a mixed-ownership port system. If this is accepted there is a case for believing privatisation may even improve allocative efficiency in the port sector. An adverse welfare implication of port privatisation relates to port development. It is maintained that private ownership is inherently less efficient than public ownership in terms of investment performance. In other words the pursuit of monopoply profit combined with the oligopolistic structure of port markets results in either over- or under-investment as compared with the social optimum. We have stressed that the investment performance of port oligopolies should be the focus of applied welfare analysis in port economics. There are a number of things that can be done on this aspect, drawing on spatial economics.

No doubt efficiency gain has been a misplaced priority of privatisation in the port industry as well as in other industries, although in public debate it has been claimed to be one of the utmost important objectives.

What can we learn from the UK 'experiment' of mixed port ownership and port privatisation? British experience stresses that privatisation could be misplaced or wasted effort if the policy objective is truly to improve efficiency. It could be misplaced effort because ownership may not be very relevant for efficiency. It could be unnecessary because public ownership is robust and can be made as efficient as private ports. Possible measures to improve the efficiency of public ports include decentralising port administration, setting up autonomous port authorities, tightening financial constraints, stimulating market competition, etc. There are even some situations in which privatisation not only does not guarantee improvements in efficiency it may adversely affect efficiency as well.

What we have learnt from the UK 'experiment' is important. While public ownership is currently an unpopular public policy option, there are a number of reasons why it may be desirable that ports should be partly or wholly retained in the public sector. These include the problem of property rights, the need for planning, the necessity of dealing with externalities and the need to promote efficiency by a public port authority (Goss, 1990, 3). It is often believed that there is a painful trade-off between efficiency and public interests. However, if the position is accepted that ownership is not always relevant for efficiency or that public ownership is robust for efficiency, a trade-off will not be necessary. Furthermore, while in this country the market ideology is so strong that people no longer worry about wholesale privatisation (including prisons and the civil services, let alone ports), in many other countries the notion of a purely private port is often not in accord with the political system or with people' beliefs. Under these circumstances, even when in theory private ownership is conducive to efficiency, any push to transfer port ownership from the public sector to the private sector would be unwise.

Efficiency and Dock Labour Scheme

The abolition of the National Dock Labour Scheme was another big event that the port industry experienced in the 1980s. The result that emerges from the comparison of productive efficiency between scheme and non-scheme ports during 1983–90 is a surprising one: the scheme had little impact on efficiency. It is only three years since the scheme has been abolished; the full effect of the deregulation in employment remains to be seen. But based on the relative performance of non-scheme ports as compared with scheme ports, it is doubtful that the demise of the scheme is likely to have a significant effect on efficiency. Although this demise has led to an enormous change in conditions of employment, it does not necessarily imply a remarkable change in the attitudes of working forces and industrial relations at the ports.

Research Work on Frontier Estimation

Half of the research work of this thesis has involved developing and estimating frontier models. Although both mathematical programming and econometric approaches have each their own advantages and disadvantages, we tend to prefer the econometric approach. The problem with the econometric approach is that an unwarranted structure may be imposed for the true frontier technology. But with the econometric approach one can test the structure specified and do something to improve or re-specify the structure. By contrast the mathematical model is rigid. When one finds the resultant efficiency estimates are not sensible (for example we found that non-parametric measures overstated the true extent of inefficiency) because of its deterministic nature, there is nothing that can be done given the data.

The work involved included Monte Carlo analysis to compare the performance of estimators and choose algorithms of non-linear optimisation, programming the maximum likelihood (ML) procedure and modelling frontiers. The corrected ordinary least square (COLS) technique performs better in small-sized samples but it is asymptotically inefficient as compared with the ML method. It seems that the likelihood function is ill-behaved. Our experience shows that the David-Fletcher-Powell algorithm is a powerful one.

Thus given the estimators available one should use larger samples whenever possible. One problem with small-sized samples (say, less than 50) is the occurrence of the wrong sign of the third moment of residuals. There are three possible explanations for this. The first is that the model is not well-specified. The second is that there is no inefficiency. The third is due to sample variation. To avoid incorrect explanations the strategy we suggest is that one should first try larger samples whenever possible before concluding that the model is inconsistent with the data or that the data reveals no efficiency.

The econometric modelling of the production frontier has been enhanced in two ways in this study. Firstly, the specification of the less restrictive reference technologies enables us to restore notions of efficiency, which are normally missing in the econometric models but can be measured in the mathematical programming models. While the modelling strategy of 'general to specific' is well accepted in other fields of applied econometrics, it has long been ignored by researchers of frontier studies. But unless the structures that we impose on stochastic frontier models are well justified we are not sure whether our efficiency estimates are sensible ones. Unlike previous studies which specified a particular structure without justification, we began with a less restrictive structure and proceeded by testing to discover whether any appropriate restrictions can be imposed to obtain a specific structure based on large-sample tests. We found that the data from our samples rejects the widely-used Cobb-Douglas model in favour of the translog specification. But we could not reject Kmenta's approximation of CES model as a restrictive version of the translog model. Efficiency estimates were thus derived from a better-specified frontier function. Secondly, the production frontier was given a dynamic interpretation and hence we are able to translate productivity growth in terms of the movement towards the frontier and the movement of the frontier itself over time.

6.4.2 Limitations Of The Study

Farrell's (1957) original intention was to measure managerial efficiency relative to the frontier production function. This is also the main concern of our investigation to compare relative efficiency of alternative forms of ownership. To estimate a frontier which can be used to measure the quality of management truly, one needs to measure factor inputs (except managerial input) correctly and exhaustively.

In view of this requirement the most serious problem of this study arises from the measurement of input and output variables. In describing the data set in Section 3.4 we have already discussed the deficiency of the data set (namely the use of a gross measure rather than the use of a net measure of output, the likelihood that port prices fail to reflect real costs, and the measurement of capital at depreciated book value). The consequence of these measurement problems may be that computed efficiency measures reflect different output mixes, different port charging policies, and different capital structures as much as or more than genuine efficiency differences. In non-parametric models these measurement errors will under- or overstate the true extent of efficiency. In parametric models, while the measurement errors may be partly captured by the symmetric error component, the systematic measurement errors (e.g. lower book-value of capital assets for ports developed a long ago) will contaminated efficiency measures. So for instance, one may have a reason to suspect the lower-than-expected efficiency score of Felixstowe (a relatively new port) and the high efficiency score of Liverpool (a relatively old port). These measurement problems may undermine the credibility of our efficiency estimates, especially when we compare ports individually. For instance we may not have sufficient faith in our efficient estimates if we compare Felixstowe with Liverpool.

These measurement problems can also obscure the implications of efficiency estimates for alternative ownership structures. Thus, for instance, a private port turns out to be less efficient than a public port, but the relative efficiency may merely reflect difference in output mix, or capital structure, or charging policy.

Nevertheless our concern is the efficiency of public ports relative to private ports. We are interested in average efficiency of each ownership group rather individual efficiency. It might be reasonable to expect that the effect of measurement problems can be reduced by averaging. Thus, for example, the lower efficiency score of Liverpool might be compensated by the higher efficiency score of Felixstowe as they both belong to the group of private ports.

A further problem arises from the fact that there are only two inputs available to us. Our frontier production models may omit some relevant variables because of lack of measurement. Location of port site is likely to be such an omitted factor. Some ports may claim their cost efficiency simply because of their superior locational advantage. For example, ports with natural deep water depth require less dredging costs, and ports in proximate to urban and industrial centres or better connected with multiple inland transport systems (e.g. railway, road, waterways, airways) need less inland transport costs. In these instances the resulting efficiency measures indicate relative locational advantage of port sites rather than relative efficiency of port management. Since the locational factor is not taken into account in our efficiency models, our deterministic frontier may well be biased in favour of ports with locational advantage or other unobserved factors. The estimated parameters of parametric models may be inconsistent because of omitted variables, and the estimates of the efficiency error distribution may be poorly determined, which is obscured by the more dominant measurement error distribution.

When information is available it would be appropriate to include a measure of location in our frontier models, both parametric and non-parametric. Given insufficient information, one way out of this problem is perphaps to use a fixed-effect frontier model by using the panel data we have. The omission of the locational effect may cause inconsistency of our estimates based on pooled data, since the efficiencies and regressors may not be independent. For locationally efficient ports tend to have higher levels of inputs through the marginal productivity conditions. But the time-constant locational effect can be eliminated in a fixed-effect model which effectively takes means over time for each port. In Section 4.5 both fixed-effects and random effects frontier models are estimated. Under the null hypothesis that there is no correlation of the inefficiencies and the regressors the general least squares (GLS) estimator is as consistent as the least-squares dummy variable (LSDV), while under the alternative hypothesis of correlation of regressors and inefficiencies the GLS as well as the ML is not. However, a Hausman test fails to reject the null. Thus sample evidence does not seem to be supportive of the possible effect of omitted fixed effects such as location. This correlates with the fact that the our estimated model by the OLS has a value of R-square as high as 96%, meaning that our capital and labour input variables are nearly exhaustive in explaining the total variation in the output variable. A 'goodness of fit measure' suggested by Farrell in estimation frontier models is uesd to check the plausibility of estimated efficiency distribution. A plausible efficiency distribution that Farrell favoured is the half-normal with mode at maximum efficiency. On Farrell's criterion, the efficiency distributions derived from the stochastic models under the exponential specification (Fig 4.4-3) is well-shaped with mode at maximum efficiency (0.90-1.00).

This does not mean, of course, one must conclude that location has no influence on port production. A more likely explanation for this might be that the locational effect is partly captured by the aggregate capital variable. For example, the value of land is based on market price, which may reflect locational advantage of port sites to some extent.

6.4.3 Recommendations For Further Studies

Much could be improved if more time were given. First of all it would be necessary and desirable to re-define and re-value the output and capital variable. The gross measure of output should be replaced by a net measure. Given the information available in annual reports and financial accounts this could be done. Some physical measure (i.e. a function of the length and the depth of quays) might be used for the capital input to replace net-book value of fixed capital assets based on historical cost. But this would involve a port-by-port study to identify quays belonging to the port authority under investigation. Furthermore, instead of using the aggregate capital measure it might be better to adopt measures of different sorts of capital (land, dock structure, machinery, buildings, ect). This may partially solve the problems arising from heterogeneity of capital inputs. Having revalued the output and input variables properly, we should have a better representation of the production frontiers for the British port industry, against which better efficiency estimates can be derived.

In estimating the deterministic frontier models we fail to take the qualitative advantage of the panel data we have. Under the assumption of constant efficiency over time, one may estimate the the frontiers from a data set of averaged input and output variables for each port over time. The most serious problem the deterministic approach suffers is its inability to tackle random shocks and measurement errors. Time-averaging should substantially eliminate random shocks and random measurement errors and hence allow a more accurate estimation of a deterministic frontier.

The panel data models we used have to assume constancy of efficiency over time. Over a long span of time periods or in dynamic circumstances this would not be a reasonable assumption. Alternative specifications allowing both cross-sectional and time-series variations of efficiency would be appropriate. For instance, a two ways fixed-effects or a two-ways random-effects models permitting both time-specific and firm-specific effects. Furthermore an unsolved problem with the dynamic frontier model is that the time trends might be overwhelmed by cross-section variation when the cross-sectional and time-series data is "fat". In addition, other specifications of time trends than the linear form might be warranted.

Constrained by the data available we have been unable to illustrate another piece of frontier modelling work, which involves decomposing the departure from the frontier into X-inefficiency and technical inefficiency. This has been done by introducing the concept of vintage capital into the frontier model. We insist that these two notions have different policy implications and that it is inappropriate to ignore the distinction between them.

Our experience shows that the measure of scale efficiency suggests an unattainable most productive scale size and hence overstates the potential for productivity improvement. An unfinished line of work is to develop more pertinent size efficiency measures based on attainable productivity. An effort has been made in Data Envelope Analysis Models (Maindiratta, 1990). Parallel work can be done in parametric models. One more line is the development of testing procedures for the appropriateness of the distributional assumption. Bauer (1990) suggested that Lee's approach (1983) and the Kappa criterion used by Molina and Slottje (1987) to test distributional assumptions about income distributions could be adopted. Furthermore, it is very likely that autocorrelation will be present when panel data is used. A dynamic specification of the frontier function that involves distributed lags may then be necessary and the appropriate estimators would need to be considered.

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