

UNIVERSITY OF TASMANIA

AN ESSAY ON THE MEASUREMENT OF PRODUCTIVITY IN PORTS

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PREFACE

Concern about the high costs incurred in Australian ports has recently been raised at a seminar on 'Shore - Based Shipping Costs' which was convened by the Bureau of Transport Economics (BTE). Although many speakers at the seminar were able to cite factors which have contributed to the current state of affairs, no general explanation of the reasons for the poor performance of the ports sector was advanced. As a reflection of this situation, the Commonwealth Minister for Transport announced after the seminar that a national Task Force would be established to investigate the reasons for high costs and delays in Australia's ports.

If it is clear that the state of knowledge about ports needs to be advanced, it is not immediately apparent how this might be achieved. This thesis sets out to assess what contribution might be provided by productivity studies which are based upon established economic theory and practice. It is noted that recent developments in this body of theory have been applied successfully in other sectors of the transport industry.

This suggests that production theory might also be applied to good effect in the case of ports. Notwithstanding this, there has been very little previous work carried out in the topic. Given this background, the aim of the present study was to explore the relevance of the theory to ports, and to propose fruitful avenues for further applied work.

The credit for generating my interest in production theory is due to John Taplin in his capacity as Professor of Transport Economics and to John Madden at the University of Tasmania. Subsequently, Associate Professor David Hensher of Macquarie University has generously given his time as an external supervisor, and I would like to acknowledge my deep gratitude for his advice and encouragement. At the University of Tasmania, assistance has been given by Tony Hocking and Dr Nick Groenewold. Finally, this thesis could not have been completed without the encouragement of my wife, Karen, and the forbearance of my children, Saxon, Chenoa, Dyani and Corwin.

PAUL HOOPER

PART A

BACKGROUND

CHAPTER I

INTRODUCTION

Poor Productivity in Australian Ports

The issue of productivity in Australian ports has been raised at various times. In the face of rapid and revolutionary changes in shipping technology and in the ways of handling cargoes, ports have invested heavily in new facilities and have substantially reduced their labour forces. Despite this, it has been persistently claimed that Australian ports are less efficient than ports in other parts of the world. In the mid-1970's, the problem was perceived to be important enough to warrant a major national study, and a Commission of Inquiry was appointed to assess the situation existing in ports. In its report, the Inquiry was lead to the conclusion that:

Concerning the overall adequacy of Australia's ports and their future needs, the strongest, most serious and most widely held view expressed was one of concern over the low labour productivity in some Australian ports and very high costs in all Australian ports. Overseas shipowners, particularly those with worldwide services to ports in many countries, made unfavourable comparisons of these factors as between some Australian ports and comparable overseas ports.

[Commission of Inquiry (1976), Page 21.]

Notwithstanding attempts to address the issue, port performance remains a serious issue. Recently, it has been reported that the charges for handling containers were about

five times higher in ports than in other land transport terminals performing similar operations¹. Although there are reasons why costs should be higher in ports, the differential appears to be too great. Supporting evidence was provided by the Chairman of the Australian National Line (ANL), who pointed out that the costs of operating container terminals in Australia were about 70 per cent higher than those in Asia². In response to claims such as this, the Commonwealth Minister for Transport commissioned a Task Force to investigate the causes of high costs and delays, and to report on ways of overcoming inefficiency.

In developing a satisfactory understanding of port production processes, the Task Force and other interested researchers have the challenge of explaining why dissatisfaction with labour productivity remains despite remarkable increases in output per unit of labour input. Over the period between 1969-70 and 1982-83, the number of waterside workers in Australian ports was reduced from 17,688 to 7,126 even though there had been an increase in the volume of trade. This represents an increase of almost 70 per cent in the number of tonnes handled per man-hour, or an annual average increase of 13.3 per cent. How, then, could labour productivity have remained low with such an apparently good record?

The Study of Productivity Relationships

Partly, the explanation of the situation described above can be found in the higher payments made to labour, a point noted by Amos (1981). However, higher wage payments do not, of themselves, lead to higher costs. Suykens (1983), for example, pointed out that wage payments in ports in Continental Europe were higher than those in the U.K., and, on his assessment, the former were more productive. Higher wage payments can simply reflect compensation for higher skills. It is generally acknowledged that waterside workers have been required to develop different skills in response to the technological changes occurring in shipping and cargo handling. In this situation, changes in the quality of labour invalidate simple productivity comparisons based on the number of tonnes handled and man-hours.

Clearly, an approach which places emphasis on the contribution of a single input, labour, to output is fundamentally flawed. A satisfactory account of the changes that have occurred in port production processes requires, at least, a knowledge of the extent to which capital has been substituted for labour. The heavy investment of capital in new ships, cranes, wharves, and other facilities and equipment has made it possible to reduce labour requirements. To some extent, it is probable that there has been some straightforward substitution involved, but it has also been the case that new technology has been embodied in the new capital equipment, affecting labour requirements and scale relationships.

From the foregoing discussion, it is evident that the growth in tonnes handled per man-hour could be attributable to several influences in addition to any improvement in the skills of labour or the intensity of work. Any rigorous study of production processes in ports must be capable of comprehending phenomena such as substitution, scale and technical progress, and must be able to identify the separate contributions of changes in the composition and quality of inputs and outputs to observed changes in productivity.

This establishes the need to base productivity studies on a firm theoretical foundation. At the outset, it is fundamental to provide an explicit statement about what is meant by 'productivity'. The approach taken herein is that the study of productivity is related to the efficiency with which inputs into an observable production process are transformed into desired outputs. One way of measuring productivity, then, is to identify differences in indexes of outputs which cannot be explained by differences in indexes of inputs. In this case, it is necessary that the index number procedures are consistent with the underlying structure of technology.

Alternatively, it is sometimes preferable to examine the structure of technology directly through a transformation function. Productivity change can then be associated

with shifts in the transformation function from a direct knowledge of the physical processes involved, as is done in 'engineering' studies, or to follow econometric approaches based on the neoclassical model of production. Both types of approach have been employed in studies of ports, although it appears that economic studies have met with less success than the engineering studies. In fact, very few serious economic studies of port production have been reported in the literature, and several prominent economists have dismissed the possibility of employing econometric tools altogether.

This situation contrasts with that in other sectors of the transport industry, where recent developments in production theory have been employed to good effect. Useful examples of this work can be found in the rail sector in Caves, Christensen and Swanson (1980, 1981) and Braeutigam, Daughety and Turnquist (1984). These researchers have been able to apply powerful tools of analysis to carefully distinguish between scale effects and productivity growth. De Borger (1984) has applied similar methods to investigate costs and productivity in regional bus operations. Caves, Christensen and Tretheway (1981) and Sickles (1985) have examined productivity change in the airline industry. Friedlander, Spady and Wang Chiang (1981) and Wang Chiang and Friedlander (1985) have significantly improved researchers' understanding of the structure of technology in the trucking industry.

Given the widespread and successful application of the tools of production theory in a transport context, and given the inadequate state of knowledge about production relationships in ports, the case for applying developments in production theory in this area requires thorough consideration.

With this background, the present study has proceeded to consider the special characteristics of ports. Shortcomings in previous studies have been identified, and more satisfactory ways of carrying out investigations have been described. In particular, the usefulness of engineering approaches to study productivity is critically examined, and the possibilities for applying the tools of economic production theory are investigated. This inevitably involves discussion of the inadequacies in the published data, and suggestions for improving data collection have been advanced.

Plan of Thesis

The thesis will be divided into three parts. Chapter II of Part A will continue to provide background material by discussing the changing role of the port as a transfer process. This will provide a descriptive account of the structure of production and will indicate important features of the port sector which need to be taken into account.

Part B will examine methods appropriate for the study of productivity. Chapter III elaborates upon the theoretical foundations for analysing productivity, and Chapter IV addresses problems in measuring the economic variables. Chapter V discusses relevant applications of the theory in a transport context, and Chapter VI then provides a critique of previous studies of port productivity.

Part C elaborates on the directions which could be usefully taken in further research. Chapter VII sets out the problem to be investigated and examines various models which could be employed in empirical work. Finally, Chapter VIII presents conclusions and recommendations.

The Glossary defines shipping and port terms raised in the text which might not be familiar to the general reader. Reference material used in preparing the thesis is contained in the Bibliography.

Notes

1. See address by Mr P.M. Brown, Director of Sealane Pty Ltd, 'The Multimodal Transport Concept and the Wharf Interface', pp. 101-102 in BTE (1984).
2. See address by Captain W. Bolitho, Chairman of the Australian National Line, page 74 in BTE (1984).

CHAPTER II

PORT TRANSFER PROCESSES

The Changing Environment

The shipping industry has traditionally been one of slow change, more akin to evolving from technological changes than to spectacular development. It is true that among the most significant changes were the development of steam propulsion and the use of iron and steel for the construction of ship hulls, but these were fairly slow to be adopted and had little effect upon sea ports. However, no change which took place during the centuries of history of movement by sea can compare with the changes which have occurred during the last fifteen years.

[Noble (1977), page 115.]

Maritime industries have undergone significant technological change in recent periods; ships have become larger and more specialized, and transfer processes in ports have drastically changed with new methods of handling cargoes. Perhaps the most important of the stimuli behind these changes has been the long-term growth in the volume of seaborne trade.

To illustrate this, UNCTAD (1974) reported that, over the period of nine years between 1965 and 1973, the volume of world seaborne trade increased by almost 100 percent. Over the same period, though, the number of tonne-kilometres increased by over 160 per cent, reflecting an increase in

the average length of haul. Given that the tonne-kilometre figures provide a better reflection of the transport task, it is interesting to note that the growth in the supply of world shipping tended to follow the growth pattern in tonnes.

This suggests that there has been a significant improvement in the productivity of shipping, ports and handling of cargo. Two of the most important influences at work over this period were the trend towards larger ships, reflecting the existence of significant economies of vessel size, and the greater specialisation in ships to serve particular trades. Since these trends have had enormous impacts on ports, it is necessary to consider them in more detail.

The underlying economic appeal of larger ships lies in their lower unit costs of construction and operation. White and Senior (1983), for example, pointed out that the cost per tonne of a tanker of size 100,000 deadweight tonnes (dwt) in 1965 was only 30 per cent of the cost per tonne of a 20,000 dwt vessel in 1955. It is possible that one of the reasons for this is that there has been an increase in the productivity of the ship-building industry, but much of the credit is usually attributed to the simple economies of larger vessels as described in Stubbs, Tyson and Dalvi (1980).

It is interesting to observe, for the class of the largest vessels, the tankers, how the trend towards increasing size emerged over time. Barsness (1974) reported that, in 1939, most tankers had a capacity of around 10,000 dwt; a vessel of 16,000 dwt was regarded then as a supertanker. By 1969, tankers of 60,000 dwt were common, and new construction produced ships ranging between 150,000 and 300,000 dwt. Since then, supertankers of 500,000 dwt have been put into service. UNCTAD (1974) reported that the share of tanker tonnage of 200,000 dwt and above increased from 30 per cent in 1973 to 36 per cent in 1974, reflecting the rapid increase in the importance of these large vessels around that period.

Similar changes were occurring in the fleet carrying dry bulk cargoes. The conventional way of carrying such cargoes was in tramp ships which could just as easily have carried any other commodities, including general cargo. The distinguishing feature was that sufficient quantity was being shipped to warrant chartering on a shipload basis. However, specialised vessels began to be used for the carriage of iron ore in bulk in ocean transport after 1945. Cargoes such as ironstone, limestone, dolomite, coal, and grain are now regarded as being suitable for bulk handling because they are capable of being loaded and unloaded at high speed by grabs, belts, conveyors, magnets, pipes and chutes.

However, it is in the area of handling general cargo that some of the most far-reaching changes have occurred. With conventional break-bulk methods of handling cargo, see Pritchard (1963), it was commonplace to handle heterogeneous cargo in small lots, often in the form of cases, cartons, drums, sacks, bales, and other types of small packages of various shapes and sizes. Each package was handled separately during loading, unloading or transshipment, the constraining factor on the size of shipment being the limit to man-handling. The technology involved in vertical lifting, the block and tackle, was generally adequate, the difficulties were encountered in moving the cargo in other directions.

Typically, sheds were close to the berth, where goods could be easily moved into a loading position underneath the crane or ship's derrick. Once conveyed to the ship in slings, gangs of men would physically stow the cargo into the holds. Unloading operations involved the same steps, except that even more sorting was involved in the sheds, the problem being to consolidate consignments for the one receiver.

During World War II the methods of handling cargo were revolutionised. Two of the most important developments were the fork-lift truck and the pallet. The fork-lift allowed for the quick movement of heavy loads around sheds and wharves, provided that physical constraints did not hinder

working. In particular, surfaces had to be relatively smooth and capable of withstanding high axle-loadings, and it was preferable to have a complete absence of pillars within the sheds. The pallet made it possible to treat heterogeneous cargo as a standard unit for shipping and handling purposes. Generally, the practice of presenting shipments in a standard form has been described as 'unitisation', the most important manifestation in the past two decades being the shipping container¹.

The first container ships were converted tonnage, and the first 'generation' of purpose-built container ships came into operation around the late 1960's². Most of these ships were in the size range between ten thousand and 25 thousand dwt, with ability to carry between 500 and 1,200 twenty-foot equivalent units (TEU's). Container vessels of the 1980's are much larger, and are capable of carrying over 3000 TEU's. Recently, even larger vessels have been ordered to commence around-the-world services in the Northern Hemisphere. It is worth noting that the containers, themselves, have also become more specialized to deal with the needs of particular commodities. Perhaps the most important trend in the future will be to a high-cube type of container which would permit faster handling and increase the scope of containers for handling loads which are now regarded as being out-size. Frankel (1983) predicted further developments in the methods of handling containers in ports, and further potential remains to exploit the container concept.

The Impacts of Technological Change on Ports

Port authorities were immediately affected by these developments. Larger ships required deeper channels and longer berths, and completely new systems for handling and storing cargo had to be introduced. Port expansion plans involved the investment of large outlays of capital in the construction of specialised facilities. In some cases, completely new ports had to be developed.

The widespread adoption of container technology in ocean trades was very rapid, and ports found that there were extreme pressures to upgrade facilities; the consequences of failing to do this was to be rendered obsolescent. Two of the most important requirements of container ports are the giant container cranes and the large amounts of land required for marshalling of containers. Dally (1973) pointed out that, in 1900, a typical berth required only one acre of land for the berth itself and attendant sheds. In 1975, a modern container berth required 23 acres for the berth and storage areas.

It was also necessary to improve the strength of wharves to cope with the heavier loads. Furthermore, the container terminal depended upon there being good access by land transport. Many of the traditional ports in inner city locations found that it was simply impossible to expand their existing facilities, and that nothing short of complete redevelopment in a nearby site was sufficient³. With

the modern container cranes capable of discharging 2000 containers in one day at a single berth, and loading a similar number, the need for large storage and marshalling areas emerged.

Within the container terminal, handling is by means of mobile equipment such as straddle carriers, side-lifters, gantry cranes, heavy-duty forklifts, and tractor-trailers. See Brown (1985). Containers can be stacked closely together in blocks of up to six units high if required, resulting in a saving in space. However, these practices have the disadvantage of higher operating costs to undertake the stacking and retrieving of containers when required.

The lack of space was at least partly responsible for the shifting of traditional functions of the ports to non-port locations. Prior to the advent of containers, it was desirable to undertake most of the cargo consolidation activities in the port area. However, the container principle made it convenient to consolidate freight in 'freight stations' or in 'inland container terminals'. See Hayut (1980). These facilities could undertake the function of packing and unpacking of smaller, less-than-container-load (LCL) consignments provided that customs clearance could also be shifted out of the port.

The ease of transfer of shipments in containers between modes has led to a fundamental change in the

relationships between a port and its hinterland. The limits of a port's traditional catchment area were bounded by the competitiveness of shipping and land transport. However, the ability to transfer freight easily between modes has made it increasingly possible to achieve a more efficient through transport system to take advantage of the economies of scale in each of the links in the transport chain. Thus, even larger ships could be constructed, serving fewer ports that are connected to trade areas by rail systems.

It is also the case that a host of new industries was spawned. Empty containers had to be cleaned and repaired and stored ready for use. Some of these activities are performed in or around port areas, some are carried out at inland terminals. One important consequence of technological change was that many berths quickly became redundant. Furthermore, the conventional ships were replaced by a reduced number of container ships, leaving a much smaller base on which ports could recoup their costs. On its own, this might not have been too drastic an effect, but attendant with containers was a rationalization of the number of ports of call. In summary, the impact on some ports was a great reduction in trade and a loss of functions from the port area.

Ports rapidly increased the amount of capital employed and reduced their labour forces. Brown (1984) reported that, in the U.K., the number of dock workers was around 80

thousand in 1955, but that the number was reduced to fewer than 20 thousand by 1982. In Australia, the number of waterside workers reached a peak of 22 thousand men, but now stands at around seven thousand men, this being despite an increase in the amount of cargo handled. This can be seen by reference to Table 2.1.

TABLE 2.1

LABOUR AND OUTPUT IN AUSTRALIAN PORTS

YEAR	NO. OF WW	MAN-HOURS (thousand)	TONNES STV/DORED (thousand)	TONNES PER WW (thousand)	TONNES PER MAN-HOUR
69/70	17688	28100	42200	2.4	1.5
70/71	16853	25100	46600	2.8	1.9
71/72	14592	20000	44700	3.1	2.2
72/73	13591	17900	41700	3.1	2.3
73/74	13375	19100	49300	3.7	2.6
74/75	13351	17800	51100	3.8	2.9
75/76	11860	12300	47700	4.0	3.9
76/77	10386	11600	50400	4.9	4.3
77/78	9823	10400	51900	5.3	5.0
78/79	9311	9900	58400	6.3	5.9
79/80	8816	9600	66800	7.6	7.0
80/81	8314	9200	65200	7.8	7.1
81/82	7944	8900	64400	8.1	7.2
82/83	7126	7700	58600	8.2	7.6

Source: Department of Transport, Sea Transport Statistics.

Organisational Responsibilities in the Modern Port

For a detailed account of the administration of Australia's ports, see Department of Transport (1981). Commonwealth Government responsibilities are largely concerned with coastal navigation aids, safety and environmental controls, survey and manning of vessels, customs and quarantine, statutory levies on the stevedoring industry, and the publication of statistics. Largely, the responsibility for administration of ports has been a matter for State Governments to decide.

In most cases, government departments or statutory authorities control ports. However, in several States, private interests have been permitted to develop and operate their own facilities, particularly for the transport of bulk ores and petroleum. In general, it is possible to identify certain responsibilities that are common to all port administrations. These relate to the provision and operation of port infrastructure, services to ships, the handling of cargo, the levying of charges, and the maintenance of records on port activities.

Australian ports vary considerably in terms of the volume and composition of their trade. Several of the large ports, in terms of tonnages handled, are associated with mining ventures, and are remote from population centres. Typically, these ports specialise in bulk handling methods

and do not require significant labour input relative to throughput. Ports serving the population centres can be described generally as multi-user ports, where facilities are required to meet the needs of a variety of ship types and sizes, different types of cargo, and different methods of handling. These ports have the most substantial assets, they serve the greater number of ship visits, and they employ most of Australia's waterside workers. It is with these ports that the greatest concerns arise about productivity.

It is also true that multi-user ports are more difficult to comprehend because of the multiplicity of functions performed within the port area by various interest groups. To an extent, it is valid to say that the port has the dual function of servicing ships and the transfer of cargo, but there are numerous sub-functions which are performed by parties other than the port authority itself. See Goss (1981) and Bird (1971).

Certain of these sub-functions can be clearly associated with the servicing of ships. In large part, the responsibility for these matters have been retained by the port authorities, or by a related body. Included in this group would be conservancy, the planning and provision of other port infrastructure, the control of shipping movements within the port, the services of pilots and tugs, and the supply of bunkers and other provisions.

The division of responsibilities for the transfer of cargo are more complex. The port authority often, but not always, has control over the provision of berths, cranes and other handling equipment, and buildings and storage areas. The port authority can also become involved in the transfer of cargo, but this role is normally confined to meeting the needs of shipments requiring special treatment. It has been traditional for the responsibility for transferring cargo to be divided between the shipowner and the consignor/consignee of the goods. The shipowner has employed the labour to stow and unstow cargo on-board the ship, whereas the shipping agent has charged the consignor or consignee for the costs of quay-side movements and storage activities.

In break-bulk shipping, the quay-side activities were usually performed on the berth and adjacent to it in sheds. Sorting of cargo was a labour-intensive and time-consuming process that was regarded as the main obstacle to greater productivity in shipping. Although there was a demarcation between the responsibilities of the shipowner, the port authority, and the shipping agent, the productivity of the port transfer process was an outcome of the combined contributions of each.

In the transfer of containerised cargoes in a modern container berth, two types of arrangement are common. Container facilities can be operated by the shipping companies

themselves, either acting individually or as a consortium, or they can be operated as multi-user facilities. Whichever is the case, it is accurate to say that an important function of the modern port is to service ships quickly. That is, emphasis is placed upon the quick transfer of cargo between ship and shore. Furthermore, the task of handling individual consignments has been shifted away from the immediate environment of the ship-to-shore interface.

The Economic Issues

The port sector has experienced remarkable technical changes in the past two decades. Superficial evidence suggests that growth in productivity has been high. However, this finding would be contrary to the common view that Australian ports remain inefficient, a situation largely attributed to poor labour productivity. For the economist wishing to make a contribution to the debate on the topic, it is apparent that the matter requires a more careful analysis.

One of the most obvious trends at work in ports has been the growth in capital employed. This suggests that capital has been substituted for labour over time. Certainly this has been the case in the transition from break-bulk methods of handling general cargo to unitised methods. However, the process of substitution has probably not been a straightforward one. Improved technology has

been embodied in the new capital equipment, and it is possible that this technological advancement has been labour and/or capital augmenting, depending upon the notion of neutrality in technical change.

Another observable feature of modern shipping is the increasing tendency to larger ships, a phenomenon which can be explained adequately in terms of economies of vessel size. It is important to consider whether there have also been economies reaped by increasing port size. Indeed, there is an argument which suggests the opposite; that is, it is claimed that ports experience a form of increasing costs. The reasoning is that, once an optimal site has been chosen and the port facilities constructed to any given scale, any further expansion will be likely to encounter rising costs. See Bennathan and Walters (1979).

Possible reasons for this are that the original site was simply the best navigable site, and that any subsequent development has to make use of less suitable land and water. Furthermore, developments tend to be attracted to sites around the existing port, thus diminishing the land available for expansion, or at least placing a high opportunity cost on it. Although these arguments are persuasive, there is no reason to believe that they are universally true, and particular ports have found that more attractive sites can be found when the need arises. Indeed, the trend in port expansion practice has moved away from the mere provision of

an extra berth to cater for trade growth, to complete development of terminals to suit new trades.

The argument does little to explain whether or not a large port possesses cost advantages over a smaller port because of its size alone. One reason why this might arise is that the number of berths do not have to be expanded in proportion to the number of ships to be serviced. Support for this hypothesis has been obtained through the application of queuing models and by making the assumption that the relevant costs to consider also include those of delays to ships. See Chapter VI.

It also needs to be appreciated that output cannot be characterised easily; all tonnes do not require the same attention in transfer. A change in the composition of trade towards tonnages that are more easily handled, for example, would show up as an improvement in productivity. This trend is particularly evident in the movement away from handling break-bulk cargo to unitised cargoes. However, even in cross-section comparisons among container terminals, any difference in the mix of empty and part-loaded containers versus fully-loaded containers would bias the results were tonnage to be used as the only measure of port output.

These considerations suggest the need to adopt a total factor productivity approach in studying technical change in ports. Within this approach, the method of analysis should be capable of testing hypotheses about substitution, scale, and technical change. Furthermore, the problem experienced in defining a uni-dimensional measure of output raises the possibility that economies of scope might also be present. Investigation of these phenomena calls for the application of powerful tools of analysis, and emphasises the need to develop a sound theoretical foundation.

Notes

1. The container has not been the only form unitisation has taken, and ports have had to cope with the needs of several types of shipping technology. Perhaps the most important one to consider is that of roll-on-roll-off (RO-RO) technology. Basically an extension of vehicular ferry services to open sea voyages, the technology is described in White and Senior (1983), Gilman (1977a), and Clarke, Thompson and Hooper (1984). Frankel (1983) also discusses Lighter-Aboard-Ship (LASH) and pallet-ship technologies. For further discussion of the container concept, see Whittaker (1975), Rath (1973), and Johnson and Garnett (1971).

2. Shipping companies possessed considerable market powers through their cartel arrangements, the shipping conferences, and were slow to take the initiative in the trend towards unitisation. When the concept of containerisation was

finally embraced, change to the new technology was rapid. See Dick (1983), Johnson and Garnett (1971), and Bird (1971) for further discussion of this matter.

3. A good example of this can be found in the case of Sydney. See Robinson, Milloy and Casling (1985).

PART B

THE STUDY OF PRODUCTIVITY

CHAPTER III

THE THEORETICAL FOUNDATION

Total Factor Productivity

Chapter II presented superficial evidence of remarkable productivity growth in ports, and yet it was also indicated that the prevailing view is that Australian ports remain inefficient. Much of the criticism is directed at labour input, despite increases in tonnages handled per man-hour in excess of 13 per cent per annum over an extended period. This apparent paradox arises as a result of well-known shortcomings of partial productivity measures. These include the failure to take account of the contribution of other factors to output, and the inability of the method to comprehend production relationships such as substitution, scale and scope, and bias in technical change.

A more satisfactory approach is to identify productivity difference as a variation in output that cannot be accounted for by a change in the quantity of inputs. All that is required to make this concept operational is a means of aggregating heterogeneous inputs and outputs in each period. Early productivity studies employed common indexing numbers, such as the Laspeyre's quantity index. See Meyer and Morton (1975) for an example. However, this approach also suffers serious flaws. Choice of a particular index

number procedure implies restrictions on the underlying technology, so that arbitrary choices can seriously mis-specify the nature and extent of productivity change.

Recognising this, it is clear that a rigorous analysis of productivity change can only proceed on the basis of a sound theory of production relationships. Since Solow (1957), it has been common to derive the necessary theoretical foundation for productivity studies from the neoclassical concept of the production function, wherein a change in productivity is associated with a shift in the production function over time. That is, if there is an n -dimensional vector of inputs \mathbf{x} required to produce output, y^t , in period t , then each period-specific production function can be written as:

$$y^t = f_t(\mathbf{x}) \quad (3.1)$$

Normally, it is assumed that Equation (3.1) can be re-written as:

$$y^t = f(\mathbf{x}, t) \quad (3.2)$$

All that is required is to assume a convenient functional form and to estimate Equation (3.2) by econometric means. Chang (1978), for example, assumed a Cobb-Douglas specification for a study of port productivity. Recent theoretical developments have provided strong justification for preferring econometric investigation of

production technologies. Furthermore, the prospects of obtaining better parametric specification of the underlying technology have been significantly improved with the development of flexible functional forms. It has been claimed that this class of functions permits the approximation of any true underlying technology (at the point of approximation).

Diewert (1981) outlined three alternative methods for studying productivity change. Two of these employ index number procedures. The Divisia index can be derived from a production function that is continuously differentiable with respect to time, and can be obtained, in practice, through choice of one of, at least, five possible discrete approximations. Diewert (1976, 1980) has explored the links between structural form and index numbers, and has developed the concept of 'exact and superlative index numbers'. By choosing an index number formula that is 'exact' for a flexible functional form, a theoretical justification exists for the choice of a particular index number formula.

Diewert's third alternative involves the use of linear programming methods. Although this method has the advantage that restrictive assumptions about the nature of the underlying technology are avoided, it is unsuitable for the present purposes because it cannot model productivity decline, and because it is complex from a computational point of view.

Another approach which has been used to identify shifts in production functions appeals to scientific knowledge of the physical production processes to yield 'engineering' production functions. See Cowing (1974), for example, for an application of this approach in the study of technical change in the steam-electric power industry in the U.S.A.. Interestingly, a number of economists, see Bennathan and Walters (1979) and Jansson and Shneerson (1982), have favoured use of engineering production functions to study economies of scale in the provision of berth space. Although there is no evidence that the engineering approach has been employed for the specific purpose of studying productivity change in ports, the interest in the approach by these economists suggests the need for closer examination.

With this background, productivity change will be associated with a shift in the production function, or, more accurately, the transformation function. In the Sections that follow, several fruitful ways of identifying such shifts will be examined in more detail. These approaches involve the use of econometric methods, index number techniques, or reference to engineering production functions.

Econometric Methods

The Basic Model

For detailed accounts of the underlying theory, see Varian (1984), McFadden (1978) and Nadiri (1981). In brief, the neoclassical approach attempts to comprehend the nature of the technology by examining the choices of production plans by profit-maximising firms bound by technological and market constraints. These assumptions focus attention on the set-efficient combinations of inputs and outputs; that is, on the technically efficient sub-set, T , of the production possibility set, P , say T . The process of transformation is then described mathematically as a mapping of variables from the input dimension to the output dimension, and is represented by the symmetrical transformation function:

$$f(\mathbf{y}, \mathbf{x}) = 0 \quad (3.3)$$

where \mathbf{y} = an m -dimensional vector of non-negative
outputs

and \mathbf{x} = an n -dimensional vector of non-negative
inputs

For a single output, y , Equation (3.3) can be rewritten as the familiar textbook representation of the production function evident in Equation (3.1).

Economic Characteristics of Production

With these theoretical underpinnings, it is possible

to proceed to estimate suitable forms for the transformation (production) function. The principal features of the technology of interest to economists include the level of output, distributive shares, scale effects, the demand for inputs, substitution, and the extent and bias in technological change. In general, these effects can be described in terms of the value of the function itself, and through the first and second derivatives. See Fuss, McFadden and Mundlak (1978).

For example, logarithmic differentiation of Equation (3.2) with respect to time yields a measure of the rate of technical change. Bias of technical change in the input dimension can be studied by reference to changes in input shares. See Nadiri (1981) for measures of input bias in the case of two factors which can be used to distinguish neutrality in technical change according to Hicks, Harrod and Solow definitions of bias. See Stevenson (1980) for a measure of bias with multiple inputs.

Substitution possibilities can also be studied in terms of first and second order derivatives. In the two input case, these are generally understood in terms of the curvature of the isoquant. A local measure of substitution is therefore provided as the proportional change in the marginal rate of technical substitution (ratio of marginal products) for a proportional change in factor proportions, the elasticity of substitution. However, in the multiple

input case, there is no obvious generalisation of this measure, it being possible to advance numerous definitions according to the number of variables held constant, and the number of variables involved in the operation. See Mundlak (1968). A commonly used measure, the Allen elasticity of substitution (AES) identifies the effect on the demand for input j when the price of input i varies, and all other input prices and output remain fixed, but allowing input quantities to adjust optimally². That is:

$$AES = \frac{\sum x_k f_k}{x_i x_j} \frac{F_{ij}}{F} \quad (3.3)$$

where,

$$F = \begin{vmatrix} 0 & f_1 & . & . & . & f_n \\ f_1 & f_{11} & . & . & . & f_{1n} \\ . & . & . & . & . & . \\ . & . & . & . & . & . \\ . & . & . & . & . & . \\ f_n & f_{n1} & . & . & . & f_{nn} \end{vmatrix}$$

and f_{ij} is the co-factor of f_{ij}

Scale effects depend upon the path of expansion, and are understood, in the case of single-output production, by reference to the effect on output when all inputs are increased by the same proportion. For the class of homogeneous functions, scale effects are easily studied, for they do not vary with the level of production. Homothetic functions allow scale to vary with the level of output. In this case, a local measure of the elasticity of scale is

provided by:

$$\mu = \sum f_i x_i / f(\mathbf{x}) \quad (3.5)$$

where $f_i = \partial f(\mathbf{x}) / \partial x_i$
 = marginal product of input i

Homothetic functions possess the property that relative marginal products of the inputs do not vary as the level of output is increased along a ray from the origin. For non-homothetic functions, there is no straightforward way of measuring the effects of all inputs by the same proportion whilst holding relative prices constant. In this case, factor-specific notions of scale are required. See Denny (1974). Returns to the individual inputs can be examined by reference to proportional changes in output to proportional changes in each input. See Nadiri (1981).

Problems in characterising scale effects are compounded when multi-product transformation functions are considered. The effects of varying inputs can no longer be observed in a single measure of output. Nadiri (1981) defined a scale function for the case when the transformation function is separable in inputs and outputs in terms of proportional changes in all outputs relative to proportional changes in all inputs. However, the possibility of changing the product mix as the level of output changes needs to be considered. Panzar and Willig (1977) introduced the notion of product-specific economies of scale. A global measure of scale, or rather, economies of scope, is provided by considering the savings achieved through joint

production. See Baumol Panzar and Willig (1982), and Bailey and Friedlander (1982).

Functional Form

In studying the relevant economic characteristics of production, the practitioner has a wide variety of specifications to choose from. See Nadiri (1981) for a survey. The choice of a particular form, to a greater or lesser extent, will constrain the range of hypotheses that can be tested validly. Put another way, to assume that certain restrictions arise in the way scale, substitution and technical change effects occur also implicitly assumes that the underlying structure of technology has a particular form. For example, the Cobb-Douglas production function requires that the elasticity of substitution between inputs is always equal to unity, and that the underlying technology is homogeneous.

Following Diewert (1971), a class of flexible functional forms has been developed which avoids many of the restrictive maintained hypotheses required in earlier work. Diewert's generalisation of the Leontief model provided a linear function which contained precisely the number of parameters needed to provide a second-order approximation to an arbitrary, twice differentiable function satisfying a minimum of predetermined conditions.

The most widely used flexible functional form, the translog, has been developed by Christensen, Jorgenson and Lau (1971) as a generalisation of the Cobb-Douglas ³. Specifically, this function can be interpreted as a Taylor's expansion of the logarithm of the function taken to the second order⁴. The general form of the multi-product translog function is:

$$\begin{aligned} \ln(f + 1) = & a_0 + \sum a_i \ln z_i + b_0 \ln A \\ & 1/2 \sum \sum a_{ij} \ln z_i \ln z_j + \\ & \sum b_i \ln A \ln z_i \end{aligned} \quad (3.6)$$

where,

$$f(x, y, A) = f(z, A) = 0$$

A = an index of the rate of productivity growth
and the vectors of inputs and outputs are re-
expressed as the vector of 'net outputs', z , and
where inputs are distinguished as negative outputs

Cost Functions

Following the pioneering work of Shephard (1953), and subsequent work by McFadden, Uzawa and others in exploring duality relationships between the various classes of functions characterising the problems of the firm, it has been common in empirical studies to investigate the structure of production through the cost function. Provided that standard regularity conditions are satisfied, duality theorems establish that all the important structural features of the production possibility set can be recovered from the cost function. See McFadden (1978).

The importance of this finding is that it is often preferable from an econometric point of view to estimate the cost function. For one thing, data on quantities of inputs and outputs are often of dubious quality, if they are available at all. Greater faith can usually be placed in price data which are freely observable in competitive markets. Furthermore, it is possible that biased estimates of the parameters of the transformation function would be obtained if there are systematic quality differences in the the variables which cannot be observed by the analyst, but which are taken into account by the managers of firms. If market prices and costs are used instead of quantities, this source of difficulty can be avoided. See Varian (1984).

The single-output cost function, $C(y^t, w^t, t)$, where w^t is a vector of input prices for period t , can be estimated directly as a flexible functional form, subject to the restriction that the function be homogeneous of degree one in prices. The translog function has the advantage that it is linear in parameters and is amenable to estimation by ordinary least squares. In practice, the number of independent parameters involved is usually large, and the possibility of multicollinearity often exists. However, factor share equations can be derived from the translog cost function by applying Shephard's lemma⁵. This yields as many additional linear equations as there are inputs without adding to the number of parameters to be estimated. Since the cost shares sum to unity, one share equation is discarded, and the remaining share equations are jointly

estimated with the cost function, thus increasing the number of degrees of freedom and the efficiency of the estimated equation. See Keaton (1978) for an application in the U.S.A. motor carrier industry.

Although multi-product cost functions can be estimated in similar fashion, a number of additional difficulties can be encountered. For example, the translog multi-product cost function requires modification in order to cope with the possibility of zero output levels. Caves, Christensen and Tretheway (1980) proposed a solution to this problem by retaining the log metric of the translog function for input prices, to satisfy linear homogeneity, and to employ a Box-Cox transformation on the output levels. That is:

$$\begin{aligned} f_i(y_i) &= (y_i^\lambda - 1/\lambda) && \text{for } \lambda > 0 \\ &= \ln y_i && \text{for } \lambda = 0 \end{aligned} \quad (3.7)$$

Caves et al found that this generalised translog cost function could satisfy the conditions of linear homogeneity in input prices given appropriate linear restrictions, and was able to deal with the problem of zero output at the cost of one additional parameter. This function was then used to investigate economies of scale in a cross-section of railway firms in the U.S.A.. See Berndt and Khaled (1979) for a simultaneous examination of returns to scale, substitution, and bias in technical change using a generalised (Box-Cox) flexible functional form in a single output context. Berndt

and Khaled's generalised function obtained parametric estimates of productivity change for non-homothetic technologies, and which subsumed several common functions, including the translog, as special or limiting cases.

Stevenson (1980) has generalised the single-output translog cost function in a different direction to investigate induced technical change. By using a truncated third-order Taylor expansion, non-time second-order coefficients could be permitted to vary, and tests for price-induced technical change could be proposed. Finally, Considine and Mount (1984) have focused upon the problem of estimating input demand functions within a dynamic setting. In this context, the adjustment process takes account of the fixity of capital stock and other factors, and about price expectations of producers. Considine and Mount rejected the use of the translog cost function in this situation and, instead, favoured the logistic function as a flexible functional form.

Index Number Methods

Arbitrary choice among common index numbers to obtain aggregate measures of inputs and outputs has been criticised by Diewert (1976, 1980) and others on the grounds that such choices imply strong (and often unrealistic) assumptions about the structure of production. An approach which derives explicitly from the production function is the Divisia index as applied by Solow (1957), and subsequently

by Denison (1962), Jorgenson and Griliches (1967), Hulten (1973) and others. In brief, the Divisia quantity index has a rate of growth equal to a weighted average of rates of growth of its component quantities, relative value shares being employed as the weights.

See Diewert (1981) for a summary of Solow's derivation of the single-output Divisia index. Richter (1966) and Jorgenson and Griliches (1967) provide generalisations to multiple output cases. The Divisia index is defined continuously in time so that, in practice, it is necessary to employ a discrete approximation. Diewert (1980) described five approximation methods, including the familiar Laspeyre's, Paasche's and Fisher's ideal index, except that the approximations are chain-linked. See Richter (1966) and Jorgenson and Griliches (1967). Unfortunately, it is known that estimates of productivity change can be significantly influenced by choice of a particular approximation method. See Diewert (1980).

It has been established, though, that the properties of the production technology can be explicitly related to the properties of index numbers. That is, functional forms, or 'aggregator' functions, can be directly related to various index number formulae. See Samuelson and Swamy (1974). With this result it is possible to choose an index number on the basis of a knowledge of the structure of the technology; all that is required is to choose an index

number formula which is exact for a particular aggregator function. However, when the structure of the underlying technology is unknown, there is a strong case for choosing among index numbers which are exact for a flexible functional form, a class of index numbers termed by Diewert (1976) as 'superlative'. These include several discrete approximations to the Divisia index; namely, Fisher's ideal index, the Törnquist, and the implicit Törnquist. See Diewert (1976, 1980), and Caves, Christensen and Diewert (1982).

One of the serious drawbacks of the Divisia index is that it is a line integral, and its value depends, in general, upon the path of integration. Thus, a cycling over the path of integration can potentially produce arbitrarily large, or small, values of productivity change. The situation in which cycling can be ruled out is when the corresponding economic aggregate does exist. See Berndt and Christensen (1973).

Another criticism of the Divisia index, as it is generally used, is that changes in technology need to be neutral in the Hicksian sense. However, Diewert (1980) has demonstrated a general case based on the modified translog variable profit function which avoids this problem. Usher (1974) further noted that the discrete approximations to the Divisia index will introduce errors which will accumulate over time. In theory, Diewert's solution should be free of this criticism. However, Diewert conceded that:

...in reality, my method is not entirely free from this criticism, since it is unlikely that my modified translog variable profit function...could provide a very accurate approximation to the actual technology for very long periods of time.

[Diewert (1980), page 494.]

Perhaps a more fundamental assumption that cannot be supported is that there is competitive price-taking behaviour, both in output markets and in input markets. This would appear to invalidate the use of index number methods in most practical situations. However, opinions differ on the strength of this criticism. Usher (1974) considered that it would not be possible to relax the conditions in the model to take account of this. In later work, Diewert (1980) expressed the contrary view.

Engineering Production Functions

Marsden, Pingry and Whinston (1974) employed an engineering approach to study unit reactors and river water quality, and contrasted their approach with the economic approach. They were particularly critical of the types of maintained hypotheses required in the economic approach in order to conform with tractable neoclassical models.

Their method involved the use of fundamental relationships established in chemical engineering and biology. Thus, the specification of the production function had a technological interpretation. Marsden et al then noted that the variables used could be linked to prices, either directly or through the use of standard formulae. It can be

remarked, though, that this step requires assumptions about the way input and output markets function. In this respect, at least, the engineering approach requires similar assumptions about markets to those made in the neoclassical models.

On the basis of their engineering functions, Marsden et al derived several well-known economic production functions, including the Cobb-Douglas form. An important finding was that the the economic models required some unrealistic assumptions about the true nature of the technology. Moreover, even simple technical specifications of the production process yielded complex formulations of economic parameters such as the elasticity of substitution. For example, the production function specified for a single reactor with only two inputs yielded a variable elasticity of substitution. Thus, economic functions such as the Cobb-Douglas might seriously mis-specify substitution possibilities even in the simplest production processes.

In defence of the economic approach, it can be pointed out that, as the production process becomes more complex, it also becomes more difficult, even impossible, to model. Furthermore, engineering functions encounter difficulties when processes are labour-intensive, and when labour is readily substitutable for other inputs. The basic approach in engineering analyses is to solve the physical problems,

and only then are labour requirements determined, usually by reference to assumed functions. Under any of the circumstances discussed here, Marsden et al admitted that economic production functions might be more useful. The improper use of physical relationships to specify a production function lacks any theoretical basis, whereas economic production functions at least are equipped to focus on the important economic phenomena. It can be added that the tools of economic analysis have improved significantly since Marsden et al's (1974) study.

Cowing (1974) provided an example of how engineering information can be incorporated within an economic approach. Cowing drew attention to two advantages of the engineering approach which were important in the case he wished to consider, the steam-electric power industry in the U.S.A.. Firstly, economic studies rely upon cross-section or time-series data which can be limited to a narrow range of observations. The engineering approach is not constrained in this way. Provided that the underlying technical relationships are well understood, it should be possible to consider all feasible input combinations. Taking this point further, if such an understanding of the production process does exist, an explicit account of the process of technical change is possible.

The central feature of Cowing's model was that it stressed the physical engineering characteristics of capital

in the form of machines. In more detail, Cowing specified a hedonic measure of capital in terms of characteristics such as capacity and efficiency. Here, the need to make assumptions about market conditions within the engineering framework was made explicit. Cowing was able to derive a cost function for capital input, and then set about solving the problem of selecting an optimal machine given expected variable costs. The resulting model made it possible to examine rates of fuel and capital augmenting technical change.

De Salvo (1969) employed an engineering approach to derive production functions for the production of tonne-kilometres per hour in railway line-haul operations. Engineering knowledge was employed to relate tonne-kilometres per hour to horse-power used and the number of cars (wagons) in the train to focus on substitution possibilities.

Overview

It is evident from the discussion above that significant advances have been made in developing tools for the analysis of productivity change. In practice, there appears to be a choice among several methods. The only one of these which purports to be able to model technology and productivity change exactly is the engineering method. However, the range of situations where this approach can be employed with any degree of satisfaction appears to be limited. Even

when the technology is well understood, functional representations can be unwieldy and difficult, even impossible, to solve. More concern is raised about the difficulty engineering studies have in modelling labour-intensive processes, a situation encountered in ports.

Econometric and index number approaches involve approximations. The index number methods have the advantage that econometric estimation is avoided, and the method is capable of dealing with a large number of inputs and outputs. Diewert (1976) has provided strong justification for choosing a superlative index number method. However, the econometric approach offers greater scope for parametric investigation of a wide range of hypotheses. Importantly, recent contributions to the theory have indicated several fruitful developments which can be used to study scale and bias in technical change. Furthermore, the econometric approach offers greater scope for permitting departure from the strict assumptions of the profit-maximising, competitive firm. This feature will be illustrated in Chapter V, when applications of alternative methods to measure productivity in the transport sector will be examined. Before proceeding, though, the problems of measuring the relevant economic variables will be addressed.

Notes

1. The possibility of productivity decline should not be dismissed. Increasing congestion in and around ports, alone, could provide a source of productivity decline.
2. It is difficult to provide an intuitive explanation of the Allen elasticity of substitution, AES, although Denny (1974) interprets it as a 'normalised price elasticity', the normalisation being chosen so that the elasticity measure does not vary with changes in the scale of units and the ordering of the two factors. Thus, the AES is defined symmetrically so that the elasticity of substitution of i for j is equal to the elasticity of substitution of j for i .
3. The Cobb-Douglas function can be interpreted as a first-order Taylor's expansion in the logarithm of the variables.
4. As an approximation, the accuracy of a Taylor's-series expansion relies upon the size of the remainder term, and it is apparent that the concept of an approximation is a local one. See Fuss et al (1978), Wales (1977) and Guilkey and Lovell (1980) for discussion of global properties of flexible functional forms.
5. Shephard's lemma establishes that the partial derivative of the cost function with respect to the input prices generate equations for the conditional demands for each of the individual factors. However, in order that a system of linear equations be derived, it is necessary to deal with the factor shares. See Varian (1984).

CHAPTER IV

MEASURING THE ECONOMIC VARIABLES

The Aggregation Issue

The need to aggregate data arises in several forms in the present context. At the simplest level, a port might consist of a single berth handling one type of good, and requiring only labour and capital input. On further reflection, labour input can be provided by workers possessing a variety of skills, including, for example, wharf labourers, foremen, electricians, and clerical workers. Capital items could include wharves, cranes, sheds, land and mobile equipment. From an econometric point of view, the estimation of a production or cost function would be made easier if the heterogeneous inputs could be aggregated, say, into capital and labour indexes.

The problems of aggregation are compounded in multi-user port where there is likely to be a number of berths serving heterogeneous goods. Consideration of productivity of the port in total requires, at least, recognition that output is also a vector which might require aggregation. To the extent that each berth represents a sub-unit of the port transfer process, a parallel can be drawn between the problem of specifying a port production process and the problem

of specifying an intersectoral production function at the macroeconomic level. See Sato (1975) and Diewert (1980).

Aggregation can be regarded as being 'consistent' when the use of more detailed information than that contained in the aggregates would make no difference to the results at hand. See Green (1964). In practice, the conditions required to ensure consistency in aggregation turn out to be very severe. Reliance either has to be placed upon the satisfaction of an external condition, price (or quantity) proportionality, or it must be assumed that the underlying technology conforms to particular conditions.

Following Hicks (1946), one basis for aggregation relies upon constancy of relative prices for the goods in the relevant group. See Diewert (1980) for proofs. Although this approach has the advantage that it does not require any restrictive assumptions about the underlying technology, it does not offer anything more than nominalistic aggregate measures. See Brown (1980). The derived groupings cannot be regarded as stable, or real, for they can be rendered meaningless by any changes in the external conditions influencing the relativity of prices.

Theoretically, a more sound basis for aggregation derives from the underlying structural features of production. That is, production relationships can be used to

suggest natural orderings of variables which permit consistent aggregation. Basic to the theory of structural aggregation is the notion of weak separability. See Green (1964), Brown (1980) and Blackorby, Primont and Russell (1978). This condition requires restrictionss on the production function in terms of the substitution possibilities between inputs in different groups. That is, it permits the production or cost function to be re-written in terms of a reduced number of arguments.

For example, the single-output production function, $y = f(\mathbf{x})$, can be re-written as a function of two groups, as:

$$y = f(h_1(x_1, \dots, x_C), h_2(x_{C+1}, \dots, x_n)) \quad (4.1)$$

where $f(\mathbf{x}) = f(x_1, \dots, x_C, \dots, x_n)$, and

provided that the groups h_i are weakly separable.

This is satisfied if:

$$\frac{\partial}{\partial x_k} \left[\frac{\partial f}{\partial x_i} \quad \frac{\partial f}{\partial x_j} \right] = 0 \quad (4.2)$$

where $x_i, x_j \in h_1(x_1, \dots, x_C)$

$x_k \in h_2(x_{C+1}, \dots, x_n)$

In practice, the conditions for weak separability are difficult to satisfy, although there is one class of cases in which some promise is apparent. Specifically, if a production process can be decomposed into two stages, one of

which produces the composite good, and the other stage combining that composite good with the other inputs, then weak separability might be satisfied. That is, the second stage of two-stage budgeting exists. See Brown (1980). Deaton and Muellbauer (1980) provide further discussion in a consumer context.

If more is required out of aggregation than is implied by Equation (4.1), then further conditions need to be imposed on the structure of production. For example, if it is necessary that sub-group costs are obtained as the products of sub-group price and quantity indexes, and that total cost is obtained by summing sub-group expenditures, weak separability is no longer a sufficient condition for consistent aggregation. With only two sub-groups, each quantity index must also be a linearly homogeneous function in inputs. That is, following Green (1964), homogeneous functional separability is required.

Given homogeneous functional separability, it is possible to derive quantity and price indexes that simultaneously accomplish the following:

- (1) the indexes reflect the optimal inputs obtained from cost minimization for homothetic production surfaces
- (2) the indexes are general and satisfy fundamental index number properties

(3) aggregation conditions are fulfilled

(4) two-stage optimization is possible

However, it is well to remember that homotheticity of the production function is required and, in addition, it is necessary to have independence between prices and quantities. Similarly, price and quantity indexes for outputs suffer the same shortcomings whenever imperfect competition exists. Thus, imperfect competition in factor and output markets can render an approach based upon homogeneous functional separability invalid. Any resulting analysis of productivity can be seriously flawed to the extent that the underlying structural hypotheses are violated. See Brown (1980) for further discussion of aggregation conditions

Empirical testing of weak separability and homotheticity tends to be difficult. Even though the development of flexible functional forms has reduced the need for many of the restrictive conditions underlying earlier work, econometric studies continue to require strong maintained hypotheses. Flexible functional forms, including the translog, generally do not impose separability restrictions on the underlying technology. However, all can generate separable structures as special cases and can be used to test for separability, noting that separability restrictions are equivalent to certain equality restrictions on the Allen elasticities of substitution.

In this regard, it is important to note that flexible functional forms approximate any underlying functional form at the point of expansion. Thus, a distinction needs to be drawn between attributing structure to the underlying functional form, and attributing structure to an approximating function. Thus, the approximation to a separable function need not itself be separable, though it will satisfy the differential implications of separability at the point of approximation.

In brief, separability of the 'true' function implies separability of the approximating function only at the point of approximation. The latter can then be expressed in terms of restrictions on parameters, and statistical tests can be carried out with and without the restrictions. If the test rejects the hypothesis of separability at the point of approximation, then it is also rejected globally. The reverse, unfortunately, does not hold; acceptance of the hypothesis of separability at the point of approximation does not have any statistical power in the global sense. See Blackorby, et al (1978).

For example, it can be shown that the translog function cannot model non-homothetic weak separability, so that testing for weak separability using the translog as an exact form is in fact equivalent to testing for a hybrid of strong (additive) separability and homothetic weak separ-

ability. Indeed, separability tests for flexible functional forms turn out to require fairly strong maintained hypotheses. This fact lead Blackorby et al to draw the conclusion that:

Partly because of the usefulness of decentralization and aggregation hypotheses and partly because of the difficulties encountered in testing such hypotheses it is no doubt the case that much empirical research will continue to be buttressed by fairly strong maintained hypotheses.

[Blackorby et al (1977), page 204.]

Output

For the purpose of productivity studies, it is important that the measure of output(s) reflects the resources required to perform the transport function. This need has been recognised, to an extent, in the widely used measure of 'tonne-kilometres'. Jara Diaz (1982) referred to this as a 'units-times-distance per unit of time (UTD)' measure. In practice, input requirements are an increasing function of both the number of units and in the distance transported, and speed of service can also be accounted for in the temporal dimension.

Although UTD measures are common, the attempt to summarise the level and the characteristics of output in a single measure can lead to seriously biased results. Concern about this matter dates back to the turn of the century, with exchanges taking place between Pigou and Taussig. See Waters (1980). Despite this, the practice of

using tonne-kilometres as a measure of transport output has persisted. Meyer and Morton (1975) provide a specific example of the biases introduced into productivity studies as a result of using this measure to characterise rail output.

It is possible that the difficulties are not so great in the context of ports because it is a transfer process involved rather than a line-haul process. That is, it appears that output can be simply measured as units handled per period. For a homogeneous cargo, such as iron ore which is being handled in bulk, the number of tonnes per annum might provide a satisfactory measure of output, one tonne of ore being exactly like any other tonne. If, however, the speed with which ships are loaded or unloaded is regarded as being an important, additional indicator of the performance of the port, a multi-dimensional measure of output is required. That is, the measure of port output would encompass the number of ships handled per unit of time in addition to the number of tonnes handled.

The matter is further complicated when the port serves heterogeneous cargoes. In some cases, output might be more appropriately measured in volumetric terms, such as cubic metres or in container movements¹. Shipments might be further distinguished as refrigerated or non-refrigerated, bolsters of timber, number of vehicles, or in a myriad of

other meaningful ways that provide a clearer description of the task required. Variations in ship size and type could also be expected to influence handling costs. All things considered, it is possible that serious biases could be introduced by treating output in a transfer process as uni-dimensional.

The foregoing discussion establishes that the output of the port should at least reflect the services to ships in addition to the transfer of cargo. In defining units for each of these outputs, ship and shipment characteristics and level of service provided should be taken into account. In practice, the vector of distinct outputs is potentially large, and some means of aggregation is necessary.

Caves, Christensen and Swanson (1980, 1981), for example, expanded their vector of rail output to include tonnes carried and average length of haul separately. This clearly involves aggregation over different types of shipments. Cairns (1981) illustrated a systematic method for reducing the vector of outputs by grouping shipments according to discrete characteristics such as commodity type, shipment weight, and length of haul. Cairns employed the automatic interaction detector (AID) algorithm to obtain groups which minimised each group's total residual sum of squares from regressions of the dependent variable, shipment cost, against various measures of transport output². Spady

and Friedlander (1978) used a single (generic) measure of output which captured variations in tonne-kilometres by obtaining an hedonic index of shipment characteristics such as size of load per vehicle (truck) and shipment size³.

Jara Diaz (1982) has criticised the use of UTD measures of transport output on the grounds that aggregation procedures have largely been arbitrary, and because the level of service affects the flow of output indicates endogeneity of output and raises consequent difficulties in the specification of cost functions. Consistent aggregation requires recognition that composition of output and network characteristics influence costs. Jara Diaz suggested that consistent aggregates can be obtained over those components of output which vary proportionally across observations, although any aggregation will reduce the ability to analyse economies of scope.

Concern about the relationship between flow and output certainly has substance in ports for the reason that port congestion does occur, and circumstances do arise where ships divert to alternative ports. Jara Diaz suggested two approaches to overcome this problem. Firstly, level of service can be incorporated as part of the description of output, as in Spady and Friedlander (1978). As an alternative, decisions on costs and output levels can be examined simultaneously in the context of the profit function. This

latter approach is less attractive from a practical point of view in the absence of reliable data on profits.

Wang Chiang and Friedlander (1984) have followed the first approach suggested by Jara Diaz by admitting several distinct generic outputs which are, in turn, obtained as hedonic indexes of tonne-kilometres and shipment characteristics. The multi-product cost function also specifically included a vector of network variables to take account of economies of spatial scope. This represents a considerable advance in the way of characterising transport output. Although the influence of network effects is not important in port transfer processes, the disaggregation of output into distinctly different classes of goods, identified perhaps in the way suggested by Cairns (1981), and expressed as an hedonic function of tonnes (or cubic metres) and in terms of shipment characteristics should provide the basis for a satisfactory approach.

Capital

Whether capital should be measured as a stock or as a flow has been a matter of considerable debate. Deakin and Seward (1969), for example, preferred to measure capital as a stock for the reason that transport operations typically require reserve capacity, and that a capital usage measure would not properly reflect the capacity of capital in any one period. Ruggles and Ruggles (1961) adopted the pragmatic view that capital stocks are more easily measured,

whereas attempts to measure the flow of capital services are open to question. On the assumption that the flow of services is proportional to the stock of capital, the matter is of little consequence. However, it is important that consistency be maintained in the treatment of output and input, so that the relevant concept of capital in productivity studies defines it as a flow of services. Furthermore, formal treatments relating capital services to capital stocks indicate that the two are not simply proportional⁴.

The problem of aggregation over heterogeneous units of capital equipment can be addressed by way of Divisia indexing procedures. To obtain an aggregate of capital stock, it is necessary to employ prices of capital goods as weights. Similarly, an aggregate index of capital service requires the use of service prices. The two aggregates cannot be regarded as being proportional to each other because of different rates of replacement and different rates of changes in the prices of various kinds of capital goods.

This is illustrated by reference to a durable goods model of capital which relates capital stock to past acquisitions of capital goods, and which associates changes in that stock with current acquisitions and current replacement requirements⁵. Replacement requirements are a function of the loss in efficiency of the capital stock for the period in question, so that replacement corresponds to economic

depreciation. As the (durable) capital good declines in efficiency, replacement is required in order to maintain productive capacity. Since the price of the capital good is the discounted value of all of its future capital services, the decline in efficiency of the existing capital good is reflected in a fall in its price. Together with a fall in price due to obsolescence, this loss in value is identifiable as economic depreciation, a component of the price of capital services. See Jorgenson (1974).

Prices for capital services can be observed directly where there are active rental markets. However, it is often the case that the users of capital services are also the owners of the capital stock. In this situation, it is necessary to calculate implicit rental prices. Christensen and Jorgenson (1973) illustrated a straightforward approach which estimates service prices (rental values) on the basis of the cost of capital, depreciation through loss of productive efficiency, taxes, and revaluation of assets. Assumptions which facilitate this approach have been criticised by Diewert (1980). In particular, the assumptions that relative efficiency of capital goods is independent of date of purchase and only a function of age, and that capital goods experience constant rates of decline in productive efficiency were regarded by Diewert as being restrictive.

These assumptions can be relaxed within a Hicksian model of intertemporal profit maximisation. According to this model, producers make production plans at the beginning of the period and extending to all future production periods. The existing stock of capital can be treated as an input in the current production period, and depreciated equipment is treated as an output which is available for production in the next period, or which can be sold if production is to be wound up. Constant 'evaporation rates' are not required, and capital goods can be distinguished according to vintage. However, as Diewert (1980) confessed, this approach is unlikely to be useful because of common inadequacies in published data.

In practice, then, the approach adopted by Jorgenson and his co-workers appears to be the most suitable method for estimating the quantity (or value) of the stock of capital and the flow of services. See Jorgenson and Christensen (1973) for a detailed description of the application of the perpetual inventory method which is used for this purpose. This approach has been widely used in empirical work, and it has the advantage that it always yields estimates of capital stocks, flows of service, and rental prices if there are time-series data on gross investment, depreciation, and prices, and if the costs of capital are known. However, the procedure admits no internal checks that would indicate any trend towards gross errors in measurement, the incremental construction involved allows errors to accumulate. Several practical problems remain; these

include the treatment of taxes and uncertainty, and deciding on the scope of capital⁶. See Diewert (1980).

Labour

Although most of the controversial issues surround the measurement of capital, a few problems remain to be considered in relation to labour input. Essentially, the task is to measure the flow of labour services. This can be done either in quantity terms or in real value terms.

Conceptually, these should give the same result. To measure the real value of labour input would require the deflation of current period labour compensation by an appropriate price deflator. This begs the question about the need to construct of an index which distinguishes quantity changes from the price changes, when it is usually possible to measure the quantity of labour input directly.

The question of which workers to include, or defining the scope of labour input, is basic to the definition of the production process involved. If a decision is made to exclude some employees, it is implied either that they belong to some other (entirely separate) production process or that they have no impact upon output. The latter assumption would generally appear to be implausible and certainly not in accord with profit maximizing or cost

minimizing behaviour. Thus, exclusion or inclusion of particular employees must be related closely to the definition of the production process itself.

One of the main issues is whether or not clerical and administrative employees are involved in the process of producing output. Sceppach and Woehlcke (1975) pointed out that some measures of productivity change, including studies by the (U.S.A.) Bureau of Labor Statistics, have only included the production workers. These authors concluded that:

This approach would probably exert an upward bias on measures of productivity change because, in general, the number of administrative, research, supervisory, and technical positions has increased relative to the number of production or on-line workers. Since all workers engaged in the industry are required to produce the service, the types of workers are substitutable to some extent, because the mix in production verses non-production workers has been changing over time, it is important that the labor input measure reflect all workers, not just production or on-line workers.

[Sceppach and Woehlcke (1975), page 29.]

Having decided this, labour statistics can then be presented in terms of the number of employees or in terms of hours worked. The former can, perhaps, be viewed as a stock variable and the latter as a flow variable. Changes in the length of the working week and in the intensity of work over a period of time need to be considered carefully before a choice is made.

Denison (1961) has considered this question in some detail. He concluded that the number of employees provided a better measure of contribution to output than hours worked, at least where changes in standard hours are concerned. He postulated that there is a relationship between output and hours per employee that conforms to the standard textbook description of a total product curve. Thus, as hours per week increase, output also increases. At some point, though, output reaches a maximum and then begins to decline. The extent to which this occurs is influenced by the fatigue of workers, accidents, and other factors such as opening and closing times and absenteeism. Thus, as working hours are reduced over time, it is possible for output per employee to be increasing, or decreasing, or staying the same. That is, work 'intensity' can vary with the number of hours worked.

In a later paper, Denison (1962) suggested that the stock of labour provides an upper bound for labour services and that the number of man-hours provides for variations in labour intensity. He then proceeded to estimate labour input by making adjustments to man-hours for variations in labour intensity. Also see Jorgenson and Griliches (1967).

Kendrick and Grossman (1980) agreed that the degree of effort expended by workers can have a potentially significant effect on productivity. However, they said that there is no good way to measure it in an aggregate sense. To

measure the effect for selected groups of workers within industries, it would be necessary to undertake work measurement studies. Sceppach and Woehlcke (1975) pointed out that there has only been a very small reduction in hours in each period, being approximately one-tenth of one hour each year in the U.S.A.. This suggests that the impact on work intensity would not be noticeable. These authors favoured the use of man-hours over employees.

The answer to the debate must ultimately rest upon careful consideration of changes in hours and output within an industry. It is also probable that general trends might have been occurring. Kendrick and Grossman (1980) noted a widespread view that there has been a weakening of the work ethic as evident in the growth in the 'leisure' industry. All of this does indicate a difficulty in using employment as a measure of the quantity of labour. Thus, following Sceppach and Woehlcke, man-hours is considered here to be the appropriate concept.

One final consideration supporting this viewpoint is that the effects of industrial action will be reflected in an hours worked concept. If there is a significant variation from one period to the next in hours lost through strikes, it is desirable to account for this directly rather than leaving it to be explained as a contributing factor to the size of the residual in conventional growth accounting procedures.

A further matter to be settled is whether man-hours should be only those which are actually worked, or whether it should include all hours paid for. Thus, the treatment of vacations, sick leave, and other paid time off is in dispute. Changes in hours worked have been occurring because of paid leave variations as much as by changes in the length of the standard working day or week. Indeed, this source of change has probably been the major one in recent periods. Paid leave includes such things as vacations, holidays, sick leave, and paid time on strike. The relevant price would be the full compensation per hour for the hours actually worked, including all fringe benefits.

Other Inputs and Overview

In early productivity studies, it was common to confine analysis to the contributions of the so-called primary factors, labour and capital. All other inputs were regarded as intermediate, and were ignored. In the first instance, it was considered that these inputs were the outputs of other productive processes. In the aggregate productivity studies which dominated the early research, it was considered that double-counting of productivity change would occur across sectors. In any case, even if it had been considered worthwhile including intermediate inputs, the data on inter-industry flows were rarely available.

It has been more common in later research to deal with productivity change at the industry, or firm level, placing greater importance on measuring the increase in productivity coming from all sources. It has also been acknowledged that there are problems in viewing labour and capital simply as primary inputs. These inputs are also dependent upon prior processes. Certainly this is clear in the case of capital equipment. However, the description of labour as 'human capital' raises the question about the definition of labour purely as a primary input.

Intermediate inputs include all products and services purchased outside the firm and include such things as materials, energy inputs, and business services, the latter including leasing charges if not already accounted for in measuring capital. In some studies, energy (fuel) has been explicitly recognized as an input and has been measured in units such as BTU's. Interest in this input has particularly grown in the transport sector following steep price rises during the 1970's and after consequent adjustments in transport production processes. Energy prices are unlikely to have exerted a significant direct impact on ports, their influence being more likely to have been felt through impacts on ship design and operation.

However, measurement problems confound the inclusion of most of these other inputs. Specifically, quantity units are difficult to conceptualize, especially where service

inputs are dominant. Published data are more likely to be available in current dollar values. Sceppach and Woehlcke suggested using specific published national deflators wherever possible, and then to apply a generalized deflator such as a wholesale price index for the unclassified inputs. Given that intermediate inputs typically would be a small proportion of total inputs, Sceppach and Woehlcke did not think that the errors that would result from ignoring them altogether would be too severe. However, there has been a general trend in business, including government business undertakings, to purchase services from outside the 'firm', the result might be to induce a systematic and upward bias in the estimates of productivity growth.

As a final comment, severe theoretical and practical difficulties arise in aggregating over economic variables. Lack of attention to these difficulties can compromise the results of applied work. Theory suggests aggregation possibilities are limited, and that tests for consistent aggregation are difficult to apply. In practice, then, aggregation should be kept to a minimum, a requirement which raises difficulties in estimation. The hedonic approach employed by Wang Chiang and Friedlander (1984) demonstrates a feasible approach which appears to overcome some of the main problems in arriving at a reduced number of economic variables. In the next Chapters, the approaches adopted in applied studies in the transport sector generally, and in the ports sector specifically, will be examined.

Notes

1. In the case of containers, the standard unit is the 'twenty-foot equivalent unit' (TEU). See Glossary.
2. The AID algorithm is a step-wise application of a one-way analysis of variance model that has the objective of partitioning a universe of objects into a series of non-overlapping clusters, on the basis of one or more discrete variables, the averages of which explain more of the variation in a dependent variable than any other set of subgroups.
3. Hedonic aggregation is described by Rosen (1980), Brown and Rosen (1982), and Diewert (1980). For a discussion in a consumer context, see Deaton and Muellbauer (1980).
4. See Christensen and Jorgenson (1973) for a thorough discussion of different concepts of capital and their uses within a comprehensive set of national accounts. Also see Young and Musgrave (1980) and Coen (1980).
5. Walters (1968) reported that parallels can be drawn between the process by which firms adjust their capital requirements and the description of the consumer's adjustment processes with the stock of consumer durables. In particular, he referred to the stock-adjustment model where in the consumer is assumed to have some preference for a particular stock of durable goods, and will in each period make gross purchases to cover physical deterioration and net additions. Although he commented that some success had been achieved with this approach, he felt that its data require-

ments limited its practical usefulness. For a discussion of the stock-adjustment model, see Deaton and Muellbauer (1980). In this context, it is worthwhile also considering the possibility of using the 'discretionary replacement model' as described by those authors.

6. Capital equipment normally includes fixed and mobile equipment, buildings and land. The tendency to purchase capital services or lease capital items potentially introduces biases into productivity studies. Whether 'capital' also includes liquid resources remains debatable. See Diewert (1980). The distinction between maintenance expenditure and investment also raises difficulties, particularly where replacement and 'betterment' cannot be easily distinguished from routine maintenance. Diewert (1980) favoured separation of maintenance and capital expenditure.

CHAPTER V

APPLICATION OF THE THEORY IN A TRANSPORT CONTEXT

Important Features of the Transport Sector

There are several features which are common to much of the transport sector which can complicate the study of production. For example, there are problems encountered in characterising transport output, a matter which was discussed in the previous Chapter. Potentially, the vector of output is a very large one, involving identifiers such as temporal and spatial dimensions in addition to commodity and shipment characteristics. Although this is not a problem which is unique to transport studies, it indicates a tendency for certain types of complications to arise in a severe form. See Winston (1985).

In addition to the problems of consistent aggregation of output, other features of the transport sector include the existence of high fixed costs, possible economies of scale and scope, and rapid output growth combined with technological change. Perhaps an even more important feature is the degree and type of economic regulation exerted by governments over transport industries. The existence of high fixed costs prevents firms from minimising total costs in each period. When economies of scale (scope) are present, markets might no longer display competitive

characteristics. Furthermore, productivity differences over time need to be distinguished from the achievement of scale economies. Output has often grown more rapidly in the transport sector, allowing new technology to be introduced quickly. See Hariton and Roy (1979). This has been particularly evident in aircraft and shipping technology, and embodied technical change and scale-augmenting technical change require investigation.

All these factors invalidate the straightforward application of the simplest type of neoclassical model. However, the effect of government regulation on the behaviour of transport firms provides additional difficulties. The purpose of this Chapter is to examine the modifications which can be made to the theoretical foundation elaborated in Chapter III. In light of these requirements, the remainder of the Chapter examines experiences in measuring transport productivity and assesses the state-of-the-art. This is intended as a bench-mark for assessing the adequacy of port productivity studies in Chapter VI.

Extending the Basic Production Model

The problem of heterogeneous output, as has been demonstrated, can be coped with by extending the basic notion of a production function to the more general multi-product transformation function. In theory, this can be accomplished within the confines of neoclassical theory. As a matter of practice, the vector of outputs can be excessive, but

aggregation possibilities appear reasonable, especially if a small number of generic outputs is used with hedonic aggregation over shipment characteristics. Network effects can also be accounted for directly.

A further problem is that the output level of the firm does not depend entirely upon prices, with level of service exercising a significant influence. See Jara Diaz (1982). If firms can decide the level of service, and so influence their demand, output is no longer exogenous. To overcome this problem, equilibrium can be studied in terms of level of service and output levels. Alternatively, the empirically less practical approach of examining the profit function is employed. In both cases, the neoclassical framework remains valid.

More serious objections to the assumptions of the model arise on the supply side. It is often the case that transport operations are capital-intensive. This is certainly the situation in railway transport, where the construction of the 'permanent way' requires substantial investments in sunk assets. Aircraft and ships are very costly items of mobile capital equipment, and common-user infrastructure in roads, airports and ports is demanding of capital resources. The importance of capital raises several difficulties. One is the practical problem of measurement as discussed in Chapter IV. A second difficulty is the fixity of costs in the short-run¹. If demand falls below

planned output, then it might be impossible for firms to adjust total costs, suggesting the need to estimate a short-run function.

Economies of scale are often associated with firm size, per se, but it is common in transport to link these to economies associated with increasing density of traffic, increasing length of haul, size of vehicle used. Economies of scope arise through production complementarities in serving networks of varying configurations and in meeting the needs of each different composition of goods. Although economists have thrown doubt on the importance of scale effects in several areas in transport, an important example being the airline industry, there remain concerns that technical change has had a scale-inducing effect. To the extent that new capital equipment has embodied new technology, and to the extent that new equipment has been larger, scale effects and technological change are strongly linked. This trend has been observed in the increasing size of commercial aircraft and ships, and there has been a tendency to increase length of trains, trucks and buses. However, given adequate data, it is possible to test for a wide range of hypotheses so that shifts along a production function can be distinguished from shifts of the function itself (technical change).

This suggests that an econometric approach should be favoured over index number approaches in order that

parametric estimates of the features of the technology can be tested explicitly. Diewert (1981) illustrated an index number approach which remains valid provided that competition exists in input and output markets and when profit-maximising behaviour can be observed. For an application of this approach, see Caves, et al (1980). However, there are situations in which these assumptions cannot be accepted, particularly in regulated industries.

In the first place, input and output markets might not be competitive. See Denny, Fuss and Waverman (1981) for a method of decomposing total factor productivity using an index number approach which reveals the contribution to output arising from departures from marginal cost pricing as distinct from scale and technical change. Economic regulation of transport has taken many forms, including direct market participation by government agencies, see Kolsen (1985), and rate-of-return regulation. In each of the cases mentioned, profit-maximising behaviour might no longer be a reasonable assumption. In the case of government agencies, minimisation of cost of providing a pre-determined level of service might remain acceptable. For rate-of-return regulation, Diewert (1981) discussed an application of the Averch-Johnson effect on econometric and index number approaches. The former requires estimation of a variable cost function, which has the advantage of being difficult to estimate if the number of time periods is small relative to the number of variable and fixed inputs and outputs. The

exact index number approach avoids this difficulty, but only in the unlikely case that the correct shadow prices of output and of capital services are known.

In general, it would appear that the neoclassical framework provides a sound theoretical foundation for productivity studies which is capable of extension when the simplifying assumptions of the basic neoclassical model are relaxed. In theory, it should be possible to examine the separate contributions of the key factors influencing productivity change. Attention is now turned on the success in applying production theory to the transport sector.

The State of Applied Work

Reviews of transport productivity studies have been provided by Meyer and Gómez-Ibáñez (1980), and Hooper (1985). Winston (1985) examined contributions in this field in the wider context of research in transport economics. Mostly, applied studies have examined productivity in highly regulated transport industries in the U.S.A. and Canada, including railways, inter-city trucking, airlines and public transport. Very few studies outside these areas have developed the art of productivity measurement beyond the analysis of partial productivity measures.

The increasing power of economic methods to provide satisfactory explanations of productivity change has been

evident in the railway studies. Commencing with work by the (U.S.A.) Bureau of Labor Statistics (1970), using the partial productivity measure, tonne-kilometres per man-hour, economists produced estimates of productivity growth which were considered to be counter-intuitive. The railway industry in the U.S.A. was a declining one, facing strong competition in many of its more lucrative markets, and suffering declining profits. Yet these studies indicated productivity growth rates well in excess of industry averages elsewhere.

This situation could be explained, in part, by the contribution of capital. Over the period in question, the railways had been investing heavily in labour-saving equipment, emphasising the need to adopt a total factor productivity approach. Kendrick (1966, 1973) calculated an index of total input using shares of labour and capital in national income to weight input quantities, and appeared to confirm the findings of the Bureau of Labor Statistics. However, later research began to indicate shortcomings in the data and in the methods used. Meyer and Morton (1975) argued that Kendrick had given insufficient attention to capital input by using inappropriate weights² and by failing to take account of the tendency to lease capital. Furthermore, the composition of output had been changing, so that railways were progressively moving towards less resource-consumptive tasks. Meyer and Morton constructed a measure of total factor productivity which compared a ratio of an

index of total output to total input. This work indicated that the railways had been achieving productivity growth rates lower than those experienced by industry in general.

Caves, Christensen and Swanson (1980) criticised Meyer and Morton's use of index numbers on the grounds that the methods used implied structural conditions which were implausible. See Chapter III. Caves et al then developed an indexing procedure which did not require assumptions of constant returns to scale, separability of inputs and outputs, predetermined elasticities of substitution and transformation, homogeneity or homotheticity of input structure, and Hicks neutral technical change. Their method commenced with a general transformation function, incorporating time as an argument, and the corresponding multi-product cost function.

The productivity index was derived through total differentiation of the total cost function and through use of an approximation method suitable with discrete (in time) data. This index could then be viewed as a function of the rates of growth of the individual inputs and outputs, using cost elasticities as weights³. See Diewert (1981) for further discussion. Outputs and inputs were disaggregated to a greater extent than in earlier studies, and Caves et al found that productivity estimates had to be revised downward to an even greater extent than suggested by Meyer and Morton (1975). Mostly, the discrepancy in the results could be

attributed to the use of inappropriate weights. However, Caves et al also demonstrated that use of a Laspeyre's quantity index resulted in an over-estimate of productivity growth of the order of 60 per cent.

In a later study, Caves et al (1981) modified their approach in order to carefully distinguish scale effects from productivity change, and to take account of the possibility that input purchases are not at static equilibrium levels. The latter possibility arises because of the fixity of railway costs, particularly in capital stocks in way and structures. Under these conditions, index number procedures were rejected, and a multi-product, variable cost function was estimated. That is, it was assumed that railway firms minimise the cost of employing variable factors given the levels of quasi-fixed factors. The variable cost function was estimated using a generalised (Box-Cox) translog form. Caves et al found strong evidence of scale economies which were related to length of haul (economies of distance).

To the extent that average length of haul had been increasing over time, scale effects were being confused with productivity growth in previous studies. This was particularly the case when industry aggregate data were employed; these data reflected little output growth at the industry level, whereas firm size was increasing through mergers and consolidations. The scale effects associated with this

growth of firm size then showed up as productivity growth at the industry aggregate level.

This emphasises the dangers inherent in using aggregated industry data, and the need to distinguish changes in scale over time from 'pure' productivity increases. Furthermore, Caves et al (1981) demonstrated that the behavioural assumptions underlying the analysis of cost functions could significantly affect results. The variable cost model consistently showed higher productivity gains than the total cost model.

These results indicate that it is both feasible and desirable for economists to relax the restrictive assumptions implicit in index number methods and in simple neoclassical models. Further developments, though, can be expected in two areas at least: in the characterisation of output; and in the behavioural specifications appropriate for regulated firms.

Diewert (1981) has discussed ways of incorporating the Averch-Johnson effect into productivity studies of regulated firms, and Considine and Mount (1984) have described a dynamic adjustment model. Friedlander, Spady and Wang Chiang (1981) examined a different approach which recognises the effect of regulation on route structure in the road transport industry, and then incorporated descriptions of

route structure directly within the cost function. Although this study did not specifically examine the issue of productivity change, the specification used illustrates a feasible approach which is an improvement over previous studies of productivity in road transport as discussed by Meyer and Gómez-Ibáñez (1975) and Hariton and Roy (1979).

Caves, Christensen and Tretheway (1981) employed index number procedures in order to examine airline productivity in the U.S.A.. All previous investigations, see Kendrick (1973) and Gollop and Jorgenson (1980), had indicated that the industry as a whole had enjoyed productivity growth rates exceeding nearly all other U.S.A. industries. Hariton and Roy (1979) confirmed this experience in Canada. Caves, Christensen and Tretheway (1981) were concerned to improve the specification of the analysis and to examine firm-specific effects. Their indexing procedures distinguished between different firms in different time periods and permitted binary comparisons of productivity. This work indicated large variations in efficiency among trunk carriers after allowing for differences in route structure and fleet composition, apparently resulting from differences in utilisation of capacity.

Braeutigam, Daughety and Turnquist (1984) shared this concern with firm-specific effects and estimated a short-run (variable) cost function at the level of a single railway firm. Following Friedlander et al (1981), level of service

was incorporated directly in the cost function as a speed variable. The function was then estimated as a variable cost translog form, with length of track as the fixed factor. Although the time-series examined was too short to provide estimates of productivity change, Braeutigam et al demonstrated that the parameters of the cost function are sensitive to level of service.

The foregoing discussion demonstrates the possibilities in analysing productivity in transport. Certainly, some researchers have met with success in improving policy analysis in regulated transport industries. There are many areas where further work can be undertaken. For example, Meyer and Gómez-Ibáñez (1975), Sceppach and Woehlcke (1975), Tomazinis (1975), Kim (1985) and Obeng (1985) have indicated ways of measuring productivity in public transport. De Borger (1984) has estimated a variable (translog) cost function for bus services, but has not explicitly accounted for level of service. In principle, though, techniques have been developed which are capable of dealing with this matter.

Meyer and Gómez-Ibáñez (1975) raised the problem of accounting for the contribution to transport productivity of capital input by the public sector in the form of improved infrastructure in roads and terminals and in traffic management. Given the paucity of relevant studies of shipping, see Johansen (1972) and Goss (1982b), the contribution of

improved ports to shipping productivity remains a matter for rigorous investigation. However, attention is now focused on the adequacy of methods used to study productivity of ports as entities in themselves.

Notes

1. That capital equipment is costly is not sufficient for costs to be fixed in the short-run. In airline operations, for example, aircraft can be exchanged or leased. On occasions, therefore, capacity can be adjusted to meet short-run changes in demand. It also can be noted that, although transport tends to be a capital-intensive activity, it often requires substantial labour input. The extent to which labour costs can be adjusted in the short term, given institutional arrangements, can influence the perceived fixity of costs. See Jansson (1979), for example, for a discussion of the implications of treating the schedule as fixed in the short-run.

2. The relative shares of capital in national income originating in the industry depended upon profitability. Since profitability was low in this highly regulated industry facing declining markets and increasing competition (from other modes), the extent of capital input was being grossly under-estimated by Kendrick. See Meyer and Morton (1975) and Meyer and Gómez-Ibáñez (1980).

3. Output cost elasticities were obtained through econometric estimation of a multi-product, translog cost function using cross-section data for each period. Cost shares were regarded as being good proxies for input cost shares on the assumption that inputs were purchased in unregulated factor markets.

CHAPTER VI

PORT PRODUCTIVITY STUDIES

Performance Studies (Partial Productivity Measures)

Examples of partial studies can be found in the work of UNCTAD (1973, 1976). The earlier of these publications introduced performance measure in the context of investigations aimed at improving berth throughput. Primary indicators focused on the process of transferring cargoes as well as the speed with which ships are serviced. Examples of the former include tonnes per working hour, and labour costs per tonne. Examples of the latter include ship turn-round time and berth occupancy. To some extent, performance measures can reflect both processes as is evident in the measure, tonnes per hour at berth.

UNCTAD (1976) elaborated upon these measures, suggesting a number of financial and operational indicators. In the first place, it was acknowledged that the handling of cargo only represented one link in a chain which also included maritime services, port navigational services, transit storage services and hinterland transport. However, UNCTAD was concerned only with the efficient management of the port's resources and confined its attention to the transfer of cargo. As a practical matter, UNCTAD preferred

to carry out analysis at the level of the individual berth, and numerous performance measures were suggested for use by port authorities. These included, for example:

- (1) tonnage worked
- (2) berth occupancy revenue per tonne of cargo
- (3) cargo handling revenue per tonne of cargo
- (4) labour expenditure per tonne of cargo
- (5) capital equipment expenditure per tonne
- (6) contribution per tonne of cargo

Australian studies have tended to focus on some measure of labour productivity. Amos (1981), for example, examined tonnage stevedored per man hour worked, and found that this statistic doubled over the decade between 1972 to 1981 for the berths serving bulk trades and trebled for berths serving other traffic. However, these improvements in productivity appear to have been dissipated in the form of higher real earnings to waterside labour. In the case of bulk trades, the cost per tonne of labour input had remained constant, and about half of the improvement in productivity in non-bulk and terminal trades had been absorbed in higher payments to labour.

The BTE (1984) has analysed productivity in container terminals using the following statistics:

- (1) number of containers handled per day a ship is at the terminal, or per hour of labour contact

(2) the amount of time a ship has to spend being unloaded and loaded

(3) the costs of terminal operations and the charges to users.

These indicators encompass the cost of the ship's time as well as the costs of handling the cargo. In addition, the BTE examined labour productivity, measured in terms of tonnes per man-hour. In the period 1977/78 to 1982/83, it was found that aggregate productivity increased from five tonnes per man-hour to 7.6 tonnes per man-hour, an increase of over 50 per cent. It is worth noting, though, that the increase in the period after 1979/80 was only 0.6 tonnes per man-hour. The BTE also found evidence that these productivity gains were offset by higher payments to labour. Importantly, they found that there was a significant reduction in the numbers employed, but there was also a significant change in the type of work performed and in the skills required of waterside workers.

Recent Australian studies by Robinson, Milloy, and Casling (1985), and by Brown (1985) have examined the issue of delays in ports. Robinson et al reported results of BTE work which compared the productivity of container terminals in Sydney, finding that there were significant differences in the time spent by ships at berths. Partly, at least, the reasons for this were revealed by examining container handling rates. The number of TEU's handled per hour of

alongside time, when compared to the number of TEU's handled per hour of actual time spent in exchanging containers, revealed the existence of significant operational and non-operational delays. To a large extent, these reflected unavoidable events. However, Robinson et al were at least able to suggest areas where delays might feasibly be reduced.

Brown (1985) drew attention to shortcomings in commonly-used performance measures, citing three main problem areas. In the first place, the importance of taking a total factor productivity viewpoint was acknowledged, given the heavy capital investment in container berths. However, the lack of data on capital did not allow Brown to pursue this approach. The second main reason for treating performance measures with caution was that like could not always be compared with like. Container terminals are often subject to very different operational and institutional constraints. For example, common-user terminals face significantly different tasks, making it difficult to achieve productivity rates equivalent to those achieved in sole user terminals. The third difficulty with commonly used performance measures lies in the interpretation of recorded data. For example, in using information about delays to loading processes, close attention needs to be paid to the conventions used by recording clerks, and to the accuracy of that data given the purposes to which it will be put.

Brown then turned attention to possible reasons for delays. Factors to do with the nature of shipping were important among these. For example, vessel arrival patterns, the mix of vessel types encountered and variations in vessel loading planning and the location of a port in relation to the ship's itinerary could have significant impacts. However, Brown also made the point that too much attention can be placed on the ship to quay interface. Delays within the terminal process also need to be considered. Inefficient terminal design and operation can cause delays to cargo and ships. Important considerations are the amount of land available relative to demand and the need to stack containers in blocks, terminal layout, and the choice of mobile equipment to effect transfers within the terminal. From this discussion, it would appear that there are substitution possibilities in terms of trade-offs between ship's time, capital for land and for mobile equipment, and labour costs.

In concluding this section, it is pointed out that the use of partial productivity measures is not favoured on theoretical grounds. Because of their ease of calculation and (apparently) straightforward interpretation, they have been widely used. The foregoing discussion has illustrated that studies employing such measures can provide some useful insights. However, more satisfactory explanations of productivity require the use of soundly-based theoretical models. Accordingly, attention is now turned to studies

which have attempted to measure total factor productivity in one form or another.

Economic Production Functions

Very few economic studies of port productivity appear to have been mounted. Deakin and Seward (1969) undertook an early study of productivity in the transport sector in the U.K.. Their analysis included a sub-group 'port and inland water transport' which was defined broadly, and included harbour, dock, canal, and lighthouses, as well as marine salvage operations, loading and unloading of vessels and the operations of tugs, barges, and ferries in ports and inland waterways. In the case of ports, output was simply measured as the total number of entrances and clearances of shipping in both foreign and coastal trade, reflecting the view that the principal function of a port is to service ships.

Chang's (1978) contribution appears to be the only published report of an attempt to estimate a production function. In this case, the primary interest was in the expansion possibilities facing ports, using the Port of Mobile (Alabama) as an example. Specifically, a Cobb-Douglas production function was estimated for the port using time series data for the period 1953 to 1973. It was noted that port labour was employed both by the port authority for the transfer of freight and by stevedoring companies for working of freight on board the ship. Only the former was included in Chang's definition of labour input, indicating

that the analysis was simply confined to the operations of the port authority itself. This was confirmed by the lack of consideration of the time spent by vessels in the port, and any systematic change in services to ships over the period would have introduced biases into Chang's results.

The estimated model took the following form:

$$R = AX_1^\alpha X_2^\beta e^{\gamma(Y/X_1)} \quad (6.1)$$

where,

R = annual gross earnings (in constant prices)

X_1 = man-years

X_2 = value of net assets (constant prices)

$e^{\gamma(Y/X_1)}$ = proxy for technical change

Y/X_1 = tonnage per unit of labour

This specification assumed Harrod-neutral technical change which was justified by noting that the capital-output ratio had remained relatively constant over an extended period of time¹. In any case, this assumption is equivalent to Hicks-neutrality in the case of a Cobb-Douglas specification. Given the usual empirical difficulty in obtaining a measure of capital input, it is disappointing that Chang did not provide any details of how the capital variable was obtained. Chang's measure of output, revenue in constant dollars, raises several concerns. The more obvious measure of tonnes handled was rejected because of the difficulty of

distinguishing trade passing through the port, but not handled. By using revenue data, Chang introduced an arbitrary means of aggregation. No account of relative changes in port charges over the period was attempted, and no discussion of the means of expressing data in constant dollar values was provided.

Chang appeared to have achieved statistically significant results, and inspection of the exponents on the capital and labour variables suggested the possibility that increasing returns to scale existed. This could have resulted from the rapid growth experienced by the port over the period, giving rise to increasing returns to the fixed assets. Chang then proceeded to establish the maximum revenue from the port subject to the estimated production function using a Lagrangian function. In this manner, the possibility of 'profitable' expansion was established². However, Chang's analysis leaves many questions unanswered. Apart from a failure to disclose details of key aspects of his study, the specification of the technology employed a restrictive functional form. Though the statistical results appeared to be encouraging, the conclusions which can be drawn from them are limited.

De Neufville and Tsunokawa have provided the most satisfying explanation of the underlying theory of productivity measurement in a ports context. These authors were interested in the production possibilities facing the Port

of Boston in its container operations. Specifically, they wanted to know whether the port was achieving efficiency in realizing those possibilities and whether economies of scale were significant.

Although these authors noted that there are strong grounds for using the cost function in econometric work, they preferred to estimate a production function for the reasons that data on costs and prices are often unavailable, whereas data on quantities are often maintained according to statutory requirement. Furthermore, even when they are available, price and cost data are often unreliable. Some of the reasons for this are that the true economic cost of the land used by port authorities bears little relationship to reported valuations, because of imperfections in the labour market, and because political factors often influence investment decisions.

Accordingly, De Neufville and Tsunokawa (1981) attempted to estimate a production function for a container port. Although the obvious unit of output was considered to be 'containers', tonnes had to be used because that was the only measure available. One implication of this is that any shift in the ratio of empty to full containers would distort the measure of productivity. Presumably, an empty container requires much the same input of resources for handling and storage as does a full container, yet it would only register around five to ten percent of the weight of a fully loaded

container. It is clear that an output measure based upon mass obscures the true relationship between the unit of handling and storage (shipment characteristics) and the input requirements.

Four major inputs were considered to be:

- (1) quay space to dock the ships
- (2) cranes to transfer the containers
between quay and ship
- (3) manpower to operate loading/
unloading processes, etc.
- (4) land on which to store the containers

Even with this reduced list of inputs, problems were encountered with the data. In the event, the number of cranes was taken as a proxy for the loading and unloading activity, including labour, and the length of the quay was taken as a single measure of the spatial dimension. Then, all combinations of quay length and number of cranes were converted into a number of 'crane equivalents'. This was made possible by assuming constant substitution possibilities over the range of output. Whether these assumptions have much validity is questionable in the light of Brown (1985). Finally, De Neufville and Tsunokawa proceeded by estimating a partial productivity measure, 'tonnes per crane equivalent', after attempting a careful specification of a production function.

Interestingly, their study of ports on the East Coast of the U.S.A. found some evidence of greater efficiency in larger ports. This was regarded as an unusual result given that the process of expanding capacity seemed to be simply a matter of replicating berths. However, a possible explanation was that larger ports might not require expansion of capacity in the same proportion as output. This follows from the relationship between variability in ship arrivals and the need to maintain spare capacity. See Bennathan and Walters (1979) and the discussion of Jansson and Shneerson (1982) below.

Zerby, Conlon and Kaye (1979) have employed a crude, but nevertheless interesting analysis of the relative efficiency of Australian ports. Although this study cannot be strictly regarded as an attempt to estimate a production function, it is interesting to examine it at this point. The study commenced by comparing the performance of berths of varying types using several partial productivity measures. Berths were categorised as container terminals, bulk loading, bulk discharging, and ordinary. Performance measures included tonnes handled per day in port (by ship), tonnes per man-hour, and tonnes per unit of labour cost. To resolve the inconsistencies in rankings yielded by these measures, Zerby et al formed aggregate indexes. The method chosen for this was to express each of the separate performance measures in standardised units, and to then sum the resulting pure numbers, or to aggregate them by an (apparently) arbitrary set of weights.

Given the exploratory nature of the work, these crude methods yielded indexes which suggested strong efficiency differences among berths of the same types. However, Zerby et al were reluctant to extend this method to examine relative efficiency of the ports rather than of the berths, except in the case of bulk handling. Analysis of variance appeared to confirm that a significant difference exists between high and low productivity ports.

This work was then extended to take account of the contribution of capital. Unfortunately, adequate data did not exist and it was necessary to obtain a proxy measure. Firstly, a cluster analysis technique was used to classify ports into groupings with similar characteristics and providing similar types of services. The proxy for capital was then computed as the sum of the means of the seven variables which provided the greatest contribution to the cluster analysis. Discriminant analysis, using this measure of capital and nine other descriptors, mainly of labour input, was employed to identify efficient ports.

In comparing the capabilities of each of their methods to categorise ports as efficient or inefficient, Zerby et al found a high degree of correspondence in their results. This gave some additional support to the hypothesis that some Australian ports are more inefficient than others. The clustering analysis apparently achieved some success in identifying groups of ports with similar functions and char-

acteristics. In identifying factors which exerted a strong influence on efficiency, work and employment practices appeared to be instrumental.

For example, ports with labour 'pools' had higher productivity. This could indicate that size of the pooled labour force provides a source of economies of scale³. Low productivity ports also tended to have an excess supply of workers with higher skills, possibly arising because of a desire to avoid delays due to shortages of specialised skills. If work practices prevent higher skilled workers performing lower grade tasks, then it is possible that excess skilled labour contributes to low productivity. However, Zerby et al's 'proxy' for capital did not exert much influence. This indicated important areas for future research: the measurement of capital input; and a satisfactory account of work and employment practices. Brown (1985) has made a contribution in the latter area, but little attempt appears to have been devoted to improving the measurement of capital.

Engineering Studies

Two basic types of engineering studies can be distinguished. The first group proceeds at a theoretical level to develop some general insights about port operations. Given this orientation, the models developed abstract from reality by making simplifying assumptions of one kind or another. Commonly, the port is viewed as a chain of links which do

not necessarily have equal capacity and which give rise to queues. Assumptions such as 'ship arrivals are random and occur according to a Poisson distribution' facilitate well-known queuing models. The alternative approach is to simulate the operations of a particular port in order to study the operational implications of a change in the configuration of the port or to study the impacts of investment proposals.

Although Imakita (1978) provided a useful review of both types of approaches and examined some of the implications for pricing policy, the only reference which has forged an explicit link between production or cost theory is Jansson and Shneerson (1982). Consequently, the model developed by these authors is of more interest here.

Jansson and Shneerson's starting point was to suggest that the port has the purpose of ensuring a 'smooth transfer of freight between sea and land transport. Although it is common in practice to find the responsibility for this to be divided among a number of parties, the precise arrangement varying from port to port, it was simply assumed that there was a 'terminal company' responsible for the complete operation, running the business in accordance with the efficiency condition that, for each given throughput, the total port user and producer costs should be the least possible.

This might appear at first sight to be an oversimplification, particularly given the expressed views of many economists that ports do not act according to commercial principles. However, Jansson and Shneerson's definition of a 'port' is a narrow one, and the assumption has greater plausibility in this case. They used the individual terminal as the unit of production, though there may be several terminals to make up the whole port. It is possible, of course, that Jansson and Shneerson's 'port' could encompass several berths which are operated jointly and which can be substituted for each other.

It was assumed that each terminal has been set up to handle a particular type of cargo in a pre-determined way, the measure of the task being in terms of throughput. This is essentially a short-term viewpoint with a category of costs taken to be fixed, including such things as the approach channel and the access by land transport. The primary inputs to the production process were considered to be capital items such as quays, port cranes, and transit storage space, although there was also a pseudo-capital group which included the cost of the ship's time and the cost of land transport. Principal inputs also included labour, both stevedoring and administrative. The cost of the delays to the cargo were not included, although this could have easily been accounted for via minor modifications.

With this background, Jansson and Shneerson's intention was to explore the general characteristics of the cost structure of ports in order that they might be able to explore the application of pricing theory in this sector. The interesting feature of this study was the explicit reference to the production function in deriving an appropriate cost function. Jansson and Shneerson specified a standard multi-input production function, but then hypothesised that it would be possible to deal directly with the demands for each of the inputs themselves (as functions of output) on the basis that substitution possibilities are limited. The important exception to this being the relationship between the amount of berth capacity and the amount of ships' time. On the further assumption that the arrival pattern of ships is random, and according to a Poisson distribution, queuing theory models can be applied to examine the relationship between the two inputs. In more detail, queuing time of ships was specified as a function of the number of berths and the pattern of ship arrivals. The form of production function (implicitly) assumed by Jansson and Shneerson was:

$$y = f(g_1(x_1, x_2), g_2(x_3, \dots, x_p), g_3(x_{p+1}, \dots, x_n)) \quad (6.2)$$

where

x_1 = berth capacity

x_2 = ship's time

x_j = other variable inputs (required in fixed proportions); $j = 3, \dots, p$

x_k = fixed inputs; $k = p+1, \dots, n$

Without any formal derivation, it was assumed that there was a dual cost function which could be expressed in the additively separable form:

$$c = h(c_1(w_1, w_2, y) + c_2(w_3, \dots, w_p, y) + c_3(w_{p+1}, \dots, w_n)) \quad (6.3)$$

where

w = the vector of input prices

Jansson and Shneerson referred to this as a long-run cost function even though several factors were taken to be fixed. On the further assumption that the 'other variable inputs' were required in fixed proportions to output, then:

$$c_2(w_3, \dots, w_p, y) = \sum r_i \cdot y \quad ; \quad i = 3, \dots, p \quad (6.4)$$

where r_i is a fixed proportion for each fixed input

The only feature of the cost function considered to be worthy of further investigation was the sub-function for the berth and ship costs. Assuming that there are constant costs in expanding berths, that berth costs are independent of ship inputs, that the cost of servicing ships at berth are constant, and that the cost of ships' time is constant, the sub-function can be re-written as:

$$c_1(w_1, w_2, y) = c \cdot n + v\lambda[q(n, \lambda) + s] \quad (6.5)$$

where

c = capital cost per berth

n = number of berths

v = cost of ship's time

λ = number of ship arrivals per unit of time

$q(n, \lambda)$ = expected queuing time per ship

s = expected service time of ships

The delay function, $q(n, \lambda)$, can then be estimated from queuing theory models. These predict that mean delay time increases as the occupancy rate of berths increases. When the port has a number of berths which can be substituted for each other, it can be shown that, for any given occupancy rate, queuing time is inversely proportional to the number of berths. Furthermore, the probability of meeting with a delay in the first place decreases with the number of berths. The combined effect is to yield a source of scale economy for larger ports. These economies can be realised either by reducing the costs of delays to ships, or by minimising the costs of providing berth capacity, or by some combination of the two.

Undoubtedly, this type of engineering (cost) function is capable of providing insights into the port transfer process, and appears to have provided some support to those empirical studies which have tentatively concluded that ports experience increasing returns to scale. However, Jansson and Shneerson's model proceeds against a background of strong assumptions. The first is that there is a production process which takes account of the cost of ships' time as an input to the process of transferring cargo. In

most cases, this would be inappropriate, and the specification of the problem would have been improved by treating the service time of ships as an output.

More serious objections need to be raised about the assumptions of constant proportions of other inputs. Although individual berths (terminals) might be designed to operate with fixed complements of inputs, it is not necessarily the case that 'other' inputs will vary proportionally with throughput. The BTE (1985) has indicated differences in the efficiency of berths constructed at different times. Brown (1985) and Zerby et al (1979) have provided evidence that different work and employment practices, and different methods of handling cargoes can give rise to different levels of performance. Finally, it has been noted in numerous studies, see Amos (1981) for example, that labour costs remain an important part of port costs.

In the discussion of engineering approaches in Chapter III, it was pointed out that successful modelling of production processes was likely to be enhanced when a sound knowledge of physical laws exists, and when the physical (non-labour) processes dominate. It must be concluded that the queuing theory model of port costs suffers serious shortcomings, and it is doubtful that it can provide a comprehensive account of the structure of port production, particularly in the study of productivity change.

A Critique

The general impression gained from this review of the literature is that the methods used to study productivity in ports have been crude in comparison with those used to study productivity in other sectors of transport. As a consequence, economists have not been able to develop satisfactory accounts of the underlying structure of technology. At best, all that has been achieved so far is to provide partial insights into the relationships between inputs and outputs. Partly, this can be attributed to a failure to apply more robust methods of analysis, but the experience of those economists who have attempted to estimate cost or production functions has not been encouraging. The main obstacles to the application of improved methods are commonly cited to be the lack of adequate data and the problems of comparability among ports. Indeed, some economists have regarded these difficulties as being sufficient justification for abandoning standard econometric approaches in favour of engineering methods.

Jansson and Shneerson's (1982) study has revealed the usefulness of the engineering method to identify possible sources of increasing returns to scale. Nevertheless, the method used could hardly be regarded as a completely satisfactory approach which could be applied to the study of productivity change. The queuing theory models do not provide a thorough description of the physical-technical processes involved, and the labour-intensiveness of ports

raises fundamental questions about the suitability of the engineering approach.

Chang (1975) has provided the only published attempt to estimate a production function for a port. The use of a Cobb-Douglas function severely limited the usefulness of that study to test hypotheses about scale and bias in technical change. Furthermore, the measure of output merely reflected one of several roles of the port; namely, it only indicated performance in handling cargo. An important dimension of output that was ignored was the service time of ships. In sum, Chang's study suffered serious flaws in its method, and questions about the suitability of the data which were used remain unanswered because of Chang's failure to reveal key details of his analysis.

The only other deliberate (published) attempt to estimate a production function, by De Neufville and Tsunokawa (1981), failed to achieve more than a partial productivity analysis. Importantly, this indicated the possibility of economies of scale. Brown (1985) and Robinson et al (1985) have attempted careful analyses of delays in ports based around the use of partial measures. Zerby et al (1979) appeared to have been able to discern efficiency differences in Australian ports. An important result of that study, though, was the development of a systematic way of grouping similar ports. Although the methods employed were

relatively crude, the expectation has been raised that econometric work can proceed on the basis that ports belong to some common population.

De Neufville and Tsunokawa (1981) rejected the use of cost functions because of the lack of appropriate data on prices and because of imperfections in input markets. If that is the case, then Varian's (1984) objection to the use of production functions needs to be heeded. Specifically, care has to be taken to ensure that quality variations perceived by managers are accounted for by the analyst. From the available evidence, it seems important to consider different skill levels of workers in different ports and between the same port at different times. Quality variation in the time taken to service ships, and the mix of ships of different types and sizes indicates the need for a multi-product function with due care being taken to quality variation.

To a large extent, adequate data on labour input and for outputs are published in accordance with statutory requirements, although they are not necessarily disaggregated to the level of individual berths or terminals. The main obstacle to the estimation of production functions is the absence of data on capital input. It is possible that this difficulty can be avoided by estimating short-run functions on the assumption that input-minimising behaviour is relevant. Even mobile equipment might be regarded as being

fixed in the short-run. However, even with this specification, period-to-period or across-port variation in the stock of fixed facilities needs to be measured.

It may therefore be concluded that data limitations pose severe difficulties in applying theoretical developments to improve the analysis of port productivity. In this situation, it is appropriate to place the emphasis on recommending ways of improving data collection and publication. A necessary first step, though, is to indicate what types of models are required. Accordingly, the next Chapter develops a more satisfactory basis for pursuing port productivity studies based upon methods used to study productivity elsewhere in transport, and then elaborates on the data needs.

Notes

(1) The early period covered by Chang's analysis pre-dated containers and the consequent impacts on ports which had only begun to take effect towards the end of the period covered. Had Chang used data for later periods, the the capital - output ratio would have changed, and the assumption of Harrod-neutral technical change probably would not have been appropriate.

(2) Interestingly, Chang found that the elasticity of revenue with respect to labour input was greater than unity, and that the marginal revenue product of labour was consistently below the wage rate. This was partly attributed to the decreasing returns and partly to controls over wages. It was also found that the elasticity of revenue with respect to capital was less than unity, but the marginal revenue product of capital tended to be greater than the cost of capital.

(3) Jansson and Shneerson (1982) have examined the possibility of economies of scale in employing labour. Support for the hypothesis can be found if all labour is permanently employed, so that the stock of labour can be treated as an fixed input. However, if work practices permit the use of wharf labour elsewhere in the port area, then the likelihood of economies of scale is diminished.

PART C

IMPROVING PORT PRODUCTIVITY STUDIES

CHAPTER VII

SPECIFICATION OF THE PROBLEM AND DATA REQUIREMENTS

The State of the Data

In every aspect, considerable scope exists to improve analyses of port productivity. The methods used in previous studies have relied mainly on partial measures, and the theoretical and econometric advances achieved in productivity measurement over the past three decades have made little impact. This contrasts with the situation in other areas of transport, where these developments have enabled economists to achieve considerable success in improving policy analysis. It has been claimed that the main obstacle to improving this situation is the inadequate state of the data. Accordingly, this Chapter commences by examining published series, and then addresses the requirements for more satisfactory analyses.

UNCTAD publishes various statistics on seaborne trade in its annual series, Review of Maritime Transport. Similar statistics are published by OECD in its annual series, Maritime Transport. Though both provide few specific details on ports, they do provide useful information about trends in seaborne trade and the changes in shipping technology and capacity. Other international (annual)

publications include Finlay's Jane's Freight Containers-Ports, Operation, Manufacturers, and Gibney's Containerization International Year Book.

More specific data are available in various published series within Australia. The Australian Bureau of Statistics (ABS) publishes detailed information on trade flows. Since much of these data are gained directly from information contained on manifests issued to customs authorities, they can be considered to be fairly reliable. The annual series, Overseas Trade Australia, contains much useful information at the commodity level and upon trade groups.

The series, Shipping and Air Cargo Commodity Statistics Australia provides data on inwards and outwards cargoes by commodities, type of ship used, type of shipping service, by port, and by trade area. More detailed breakdowns are also available on microfiche. Again, these data are obtained from customs records, but they also encompass information gathered from Lloyd's Register of Shipping, from the Australian Department of Transport and from other ABS series collected directly from the shipping companies. Shippers, or their agents, are required to submit details of each vessel's arrival or departure at an Australian port, whether or not overseas cargo is discharged or loaded. Specific details for overseas trades are also published in the Quarterly series, Shipping and Cargo Australia. The annual series, Overseas and Coastal Shipping, also provides

details of tonnages through Australian ports, but these are not linked to commodity data.

The annual series, Port Authority Cargo Movements, includes statistics on the flows of cargoes between origin and destination ports by broad commodity classifications according to the Australian Freight Commodity Classification (ATFCC). These data are obtained directly from the individual port authorities. This gives rise to some inconsistencies, particularly in amounts recorded as being loaded for a destination port compared to amounts recorded as coming from the origin port.

One problem with these data is that the tonnage figures have not always been reported on a consistent basis. It was a common practice for port authorities to report statistics in terms of revenue (cargo) tonnes, a hybrid measure of mass tonnes (deadweight) and volume in cubic metres. Cubic metres and tonnes were simply added to arrive at revenue tonnes. This reflected the practice of levying shipping and wharfage charges according to the density properties of the cargo. Commodities having a density of less than one tonne per cubic metre, such as motor vehicles, were either measured directly in units or in cubic metres. However, in June 1977, the Australian Association of Ports and Marine Authorities (AAPMA) adopted a policy that all port cargo statistics would be published in mass tonnes. The

1980-81 publication of Port Authority Cargo Movements commenced reporting all statistics in this consistent form, with prior editions having some inconsistencies.

The problem of mixing mass and revenue tonnes is probably not a serious one in a general sense because the greater amount of cargo moved by sea was likely to be measured in mass. The problem was likely to be most severe in the case of general cargo. However, one major discrepancy was noted to arise because of the practice of assuming that one kilolitre of liquid was equal to one tonne, irrespective of the density of the liquid. Since petroleum has a density of less than unity, this practice gave rise to considerable overstatement of petroleum cargoes, particularly for the lighter refined products. As the major exporting port, Westernport, reported its statistics in mass tonnes, the problem is not severe.

The Department of Transport also publishes separate statistics pertaining to the coastal trades. In 1983, it released Coastal Freight Transport Task Estimates Australia 1971-72 to 1981-82, and has subsequently released Coastal Freight Australia 1982-83. Although drawn from the same sources as the Port Authority Cargo Movements, they contain useful summary tables and also include estimates of tonne-kilometres.

From the foregoing, it is apparent that there are adequate statistics on the volume of trade through ports, with data drawn from different sources available for cross-checking. The major problem is that it is not possible to investigate productivity at the individual terminal level on the basis of these data, and recourse would have to be made to reports issued by individual port authorities or terminal operators. Generally, data are seldom published in detailed form at this level.

At the individual port level, it is fortunate that statistics are also available on stevedoring labour input. The Department of Transport releases statistics on man-hours worked, earnings of waterside workers, time lost through industrial disputes, and vessel working visits for individual ports in the annual series Sea Transport Statistics. These data are collected under the Port Statistics Act 1977, and the Department of Transport has been responsible for their collection and publication since December 1977. Prior to that, these statistics were collected and reported by the Australian Stevedoring Industry Authority under the provisions of the Stevedoring Industry Act 1956. Of course, it might not always be the case that all, or any, stevedoring labour would be included in the analysis of a port's production processes. Furthermore, data on non-waterside labour input would still need to be obtained from other sources. The most likely places to obtain this information would be from the individual port authorities and/or

terminal operators, although examination of annual reports and other port publications reveals that such data would have to be extracted from each port authority's internal records as a special task.

One of the most common complaints is that data on capital input are unavailable. Apart from any theoretical difficulties in forming a capital stock or capital services aggregate, the difficulty is that even the most rudimentary statistics are not available. Port authorities do not publish details of capital expenditure in any consistent fashion, and it is difficult to obtain information on the expenditure on individual berths. In many cases, investment is undertaken by the port users themselves. In practice, the compilation of a series on capital input would be a daunting task, requiring compliance of port authorities, terminal operators, stevedoring companies, and major shippers.

So far, most of the attention has been directed towards information on quantities, although series on payments to waterside labour have been noted. Unfortunately, information on input prices and costs is, as De Neufville and Tsunokawa (1981) observed, rarely available. Port authorities publish annual reports which do contain data on expenditure, but usually in highly aggregated form. The derivation of non-waterside labour input prices, and unit prices of maintenance expenditure might prove to be difficult.

The overall picture is that there are reasonably good statistics on output and labour input, quantities and prices, particularly at the port level of aggregation. Empirical studies, though, are likely to remain hampered by deficiencies in the data on capital, maintenance, on other labour input quantities, and on prices. The following Sections proceed to examine the prospects for improving the specification of port production (cost) studies against this background.

Stating the Problem

Although it is fundamental, few of the published studies have commenced with a clear statement of the problem to be investigated. The major aim, if only made implicitly, is to provide a way for carrying out meaningful comparisons of efficiency among ports, and to examine efficiency differences over time. In particular, the role of wharf labour requires examination. This much is straightforward. However, deciding upon the proper definition of the 'port' is invariably overlooked.

The underlying assumption in production theory is that there is a decision-making entity which efficiently controls the resources of the port. It is worth noting, then, that the basic responsibilities of port authorities are to provide services to ships and to ensure that facilities exist for the transfer of cargo between sea and land. The employment of waterside labour is frequently undertaken by

stevedoring companies or by individual terminal operators. In view of this, there are at least three bases on which port productivity studies can proceed. Firstly, the performance of the port authority itself can be examined. The second type of study would use the individual berth or terminal, or even the stevedoring company, as the unit of analysis. In both of these cases, an individual entity would be examined. However, it is often of interest to compare the overall performance of ports, so that a third type of study assumes some underlying, aggregated production function.

Port Authority Performance

There are at least two reasons why the performance of individual port authorities should be of interest. In the first place, economists have indicated concern that port charges do not reflect normal commercial principles, presumably meaning profit maximisation, and that they do not ensure allocative efficiency due to departures from marginal cost pricing rules. See, for example, Heggie (1974), Bennathan and Walters (1979), and Thomas (1981). These analyses have proceeded mainly on the basis of descriptive accounts of the structure of port costs. Clearly, the development of soundly-based cost functions would enhance debate on this subject.

The second reason for examining individual ports is to study the potential for reducing charges through

amalgamations and rationalisation of administration. The possibility that ports experience decreasing costs has been raised in the previous Chapter. Specifically, ports might not need to increase the number of berths in proportion to the number of ship visits. Another reason why larger ports can have lower unit costs has to do with the efficient use of skilled personnel. For example, smaller ports might not be able to carry out planning, engineering and maintenance functions as efficiently as larger ports.

In theory, it is possible to specify a production function, or its dual cost function, for an individual port authority. This, at least, requires cost minimising behaviour on the part of port managers¹. One problem with this assumption is that ports require substantial fixed investments in approach channels, the harbour basin, and on berths and adjacent land. The cost of capital services might then be difficult or impossible to adjust for period to period changes in the flow of trade. In this situation, the cost function should be specified as a short-run (variable) cost function subject to the supply of fixed factors. This, in essence, was the approach adopted by Jansson and Shneerson (1982), except that they jointly optimised port and shipping operations.

Caves, Christensen and Swanson (1981) ruled out the possibility of applying index number approaches in circumstances such as this, and suggested a generalised form of

the multi-product translog variable cost function. De Borger (1984) has applied a similar model in bus operations. De Neufville and Tsunokawa (1981) objected to the use of cost functions for port studies because of the lack of reliable data. However, cost functions are to be preferred from an econometric point of view. This emphasises the importance of improving data collection and reporting for series on prices and costs.

In general, the variable cost function would be of the form:

$$C_V = f(y, w_V, x_f, t) \quad (7.1)$$

where

C_V = variable cost

y = vector of outputs

w_V = prices of variable inputs

x_f = quantities of fixed inputs

t = time

In practice, it would be desirable to have the vector of variable inputs which employed a disaggregated labour input to reflect specialist skills of different types of workers. Given detailed reporting requirements, there seems to be no natural difficulty in obtaining satisfactory input price data. Greater difficulties could be encountered with other current inputs, particularly with expenditure on maintenance. The purchase of materials or services might not factor easily into unit prices and quantities. An

expedient approach might be to calculate the cost of maintenance per berth, or per crane.

The remaining data needs are quantities of output and quantities of fixed inputs. Quantities of fixed inputs can be expressed in physical terms, such as the number of berths, the number of cranes, and area for storage. Caves et al (1981) maintained a vector of four output indexes. In theory, it might be necessary to consider a much larger vector for a general purpose port.

In the first place, a distinction can be made between services to ships and services to cargo. In the short-run, costs might be found to vary closely with the number of ship visits. The remaining elements of output could then reflect cargo handling activities. Zerby, Conlon and Kaye (1979) indicated that a distinction needs to be made between bulk-loading and bulk-discharging. Further problems can be encountered in trying to reduce the number of distinct cargoes down to a reasonable number of indexes. Numbers of live-stock, numbers of vehicles and machinery are not easily converted into meaningful measures in terms of tonnages or cubic metres. Consequently, some difficulties in dealing with the output vector can be anticipated, especially with studies of smaller ports where productivity estimates might be expected to be sensitive to changes in the composition of trade. Possibly, the hedonic approach of Wang Chiang and Friedlander (1984) could offer some sort of solution. That

is, it might be possible to reduce the vector of outputs to a smaller number of indexes, each expressed as an hedonic function of shipment characteristics.

In conclusion, the theoretical prospects for examining the performance of individual ports appears to be promising. Using pooled cross-section and time-series data, Caves et al (1981) demonstrated that a variable cost function, estimated as a generalised (Box-Cox) translog form, is capable of identifying the separate influences of scale and and productivity change. The modifications suggested by Wang Chiang and Friedlander (1984) should make it possible to investigate changes in the mix of trade to identify the existence of economies of scope.

Productivity of Berths

Most ports provide a number of berths which can vary in kind from general cargo wharves, to bulk loading/discharging berths, and to container terminals. The latter require marshalling areas for temporary storage of containers, mobile equipment for transfer of containers around the terminal area, and container cranes and Ro-Ro facilities for loading/discharging of ships. Container terminals require significantly greater labour input than do bulk terminals, and it is common in port productivity studies to focus on container terminal operations.

To the extent that the container terminal is operated as a separate entity, it represents the least aggregated basis on which productivity studies can proceed, taking as an assumption the notion that some decision-making unit is attempting to pursue optimising behaviour. An important distinction, though, can be drawn between those terminals which are operated as common-user facilities, often provided by the port, and dedicated facilities under the direct control of a shipping line, or a group of related shipping companies. Presumably, the owners of dedicated facilities are attempting to optimise the joint operation of ships and terminals. From the queuing theory models, it appears that there is some scope for reducing delays to ships by controlling arrival patterns. Whether this is possible in practice depends much upon the vagaries of weather, the effects of industrial actions, and other sources of delay. Service times of ships in dedicated terminals can also be reduced through standardisation of vessel loading plans, thus enabling optimisation through computer modelling. See Brown (1985).

The foregoing discussion does not necessarily preclude studies of dedicated terminals, for it might remain a plausible hypothesis that the terminal is attempting to minimise its costs subject to the determination of a service level. However, there are sufficiently strong grounds for maintaining a distinction between the two types of terminals.

Given the substantial investment in fixed assets and the inability to adjust capacity to temporary fluctuations in trade, short-run cost minimisation appears to be the most reasonable working hypothesis. Fixed inputs would include the number of berths, the number of cranes, and the amount of storage and marshalling space, although it might be possible to vary these in the medium-term. Whether mobile equipment can be regarded as being fixed for any one period is questionable. Brown (1985), for example, discussed the flexibility of van carriers in performing a variety of tasks, raising the possibility that the number of items of equipment actually in use can be readily varied. A distinction, at least, needs to be drawn between the various types of mobile equipment, and basic research needs to be carried out to determine whether the flow of services can be adjusted in the short-term. It would be of particular interest to assess whether usage rates diminish working lives.

Subject to this matter being resolved, the variable cost function could be specified as in Equation (7.1) and estimated using pooled data in similar fashion to Caves et al (1981). Given the finding by Zerby et al (1979) and Brown (1985) that work practices in individual ports can have a significant impact on performance, the necessity for taking account of 'firm-specific' differences needs to be taken into account. A particular feature of the Caves et al method was that it used data on individual firms rather than relying on industry averages.

Output definition would need to include services to ships, but it might also be necessary to account for the itineraries on port operations. Depending upon the pattern of visiting a group of ports, an individual port might find itself confronted with a more or less difficult task in loading and discharging cargo. Furthermore, size and type of ship could be expected to influence costs. Regarding the transfer of cargo, the distinction between full and empty containers, though relevant to the shipping companies, is probably not useful for the present purposes. However, different sizes and types of containers might affect costs in different ways. It is common practice to calculate the number of 'twenty-foot equivalent units'. However, the basis of conversion requires testing to see whether a consistent aggregate results.

If these arguments are heeded, the required vector of outputs could be large. It would be desirable for the vector of inputs to distinguish among workers with different skills. Given that the number of container terminals would be limited in a cross-section limited to Australian ports, the econometric difficulties would be considerable. One approach would be to maintain generic outputs, such as ships serviced and containers, and to estimate each generic output as a hedonic function of the number of units and their characteristics. Following Wang Chiang and Friedlander (1984), the output vector, y , could be replaced by Ψ , where:

$$\begin{aligned} \psi_1 &= (y_1, k_1) \\ \text{and} \quad \psi_2 &= (y_2, k_2) \end{aligned} \tag{7.2}$$

where,

y_1 = number of ships serviced

y_2 = number of containers

k_1 = a vector of service characteristics (ships)

k_2 = a vector of container characteristics

Further econometric problems could be encountered because of the lack of variability among ports of similar vintages. Robinson et al (1985) have discussed relative efficiency of container terminals of different vintages, but the number of observations of markedly different ports would remain small. In this case, multilateral comparisons might be required, raising further problems in ensuring that systematic biases are not introduced into price and cost data drawn from different countries.

Port Production Studies

Studies which examine the performance of individual port authorities have relevance to policies on rationalisation of port administration. Studies of individual terminals can be employed as benchmarks of performance, but they could reveal potential savings arising from rationalisation of the number of terminals within a port, or through a reduction in the number of terminals of a given type across a number of ports. In some situations, though, it is of more interest to consider the productivity of the port taken as a whole, particularly where there is some prospect for

rationalisation of the number of ports, or a desire to influence plans for expansion.

If a single port body owned, maintained, and operated all of the berths in the port, including the employment of stevedoring labour, there would be little theoretical difficulty in proceeding. In most ports, though, this is not the case. Container terminals can be operated for the exclusive use of a group of shipping companies. Stevedoring companies can provide the labour input. The port, then, must be considered as an aggregate entity, and the specification of a port cost (or transformation) function raises problems similar to those involved in aggregation over sectors. The difficulties involved here can be considerable, particularly when profit-maximising behaviour cannot be maintained as an hypothesis, and when some capital inputs must be regarded as being fixed. See Diewert (1981).

In view of these matters, it is desirable to confine studies at the aggregate level to the simplest types of situations. These can be observed where the port assumes a major role, and where there is a minimum of dedicated facilities under the control of other parties. In this case, port productivity studies raise fewer theoretical concerns, and appear to be valid for smaller ports. It is worth noting that several important policy issues on port rationalisation are raised at this level.

The starting point, as above, is to assume that there exists a variable cost function derived from a transformation function subject to fixity in one or more inputs. Following Caves et al (1981), a generalised translog functional form could then be estimated using pooled data. One problem would be to ensure that ports are, at least, roughly comparable and drawn from the same population. The results of Zerby et al (1979) have suggested natural groupings for this purpose on the basis of a systematic approach. The cluster which displayed the greatest intra-group similarity included the Tasmanian ports of Hobart, Burnie, Devonport, Launceston, Stanley and King Island, and also included Westernport, Darwin and Thursday Island. Although these ports vary in scale, they are relatively small ports. Importantly, the question of rationalisation has been raised on numerous occasions in relation to Tasmanian ports. For the purposes of an exploratory study, this group could be of interest.

On further inspection, these ports handle diverse cargoes, including bulk liquids and solids, containers and other general cargo, timber, steel, newsprint, vehicles, and livestock. Devonport also serves passengers. Zerby et al indicated the need to distinguish between bulk loading and discharging, adding to the size of the output vector. Given the size of the sample, it would be desirable to consider using a small number of generic outputs, possibly estimating these as hedonic indexes. If possible, it would be desirable to distinguish the following:

- (1) number of containers
- (2) number of vehicles
- (3) number of livestock
- (4) other cargo in tonnes or cubic metres
- (5) passengers
- (6) services to ships

Fixed inputs would include the number of cranes, the number of berths, and the amount of land required for storage and marshalling. Variable inputs would include port authority labour, possibly distinguished according to clerical and planning/engineering, and waterside labour. Other variable inputs would include maintenance expenditure expressed, as before, on a per berth or per crane basis. A less straightforward input is mobile equipment. In the first place, the number of machines might be fixed in the short-run. Secondly, actual use of the fixed stock of machines could vary, with the possibility arising that the same machines could be used productively in non-port applications. Finally, economic depreciation might be directly linked to use of these assets so that service prices are directly related to use.

This discussion has so far yielded six output variables, two measures of fixed capital, four categories of labour, two types of maintenance costs, and machine hours. The problem is then to estimate a large number of parameters with a relatively small sample. However, any success in

estimating a cost function along these lines would represent a significant advancement over previous studies.

Overview

Three different bases for advancing port productivity studies have been discussed. In view of the importance attached to waterside labour input, it is likely that any emphasis, in practice, would be devoted to analyses of berths/terminals or of ports. The difficulty of obtaining appropriate data at the level of the berth probably means that productivity studies will proceed mainly at the level of the port, even though this requires aggregation over separate economic units. The approach suggested above is to concentrate, at least in the exploratory stage, on smaller, less complicated, ports. Zerby et al have identified such a grouping which consists mainly of Tasmanian ports.

Taking this group, series on output and waterside labour input can be obtained from published reports. Remaining details of fixed inputs, variable costs, and prices of non-wharf labour and maintenance inputs would have to be extracted from port authority records. On this basis, it appears feasible to develop the necessary panel data to estimate a variable cost function. If econometric estimation proves successful, then it should be possible to examine substitution, bias in technical change, and scale effects with a greater degree of rigour than has hitherto been possible. Nevertheless, much would remain to be done to ensure

that data are improved. Walters (1971) and UNCTAD (1976) have designed systems for collecting port and shipping statistics. Although these require some modifications to ensure that adequate statistics on prices and costs are obtained, and that non-wharf labour inputs are measured, their adoption can only be recommended.

Notes

1. Ports are generally managed as public undertakings, although the precise form of organisation can vary considerably. See Department of Transport (1981), Cumming (1977) and Goss (1981). Profit-maximisation is likely to be implausible in this case, although cost minimisation might be acceptable as a working hypothesis. There appears to be little justification for applying the Averch-Johnson model of the regulated firm. See Diewert (1981).

CHAPTER VIII

CONCLUSIONS

The maritime sector has undergone major changes in the previous twenty years. In particular, the trends towards larger, more specialised, and faster ships, handling loads in bulk or in unitised form have had far-reaching implications. Ports were directly affected. Larger ships often required deeper and wider channels. Berths had to be extended to cope with increasing numbers of ships of larger dimensions; larger cranes and bulk loading facilities had to be provided; and storage areas in the precincts of the port had to be expanded. In some cases, existing ports proved to be inadequate; their choice was either to relocate and to construct new facilities, or to become redundant. These requirements necessitated substantial investments in fixed facilities. At the same time, shipping operators were rationalising the number of ports included in their itineraries, and the prospects were that there would be a smaller number of (larger) ships upon which revenue could be earned to cover the costs of expansion.

Against this background, the upsurge in interest of economists in the pricing and investment behaviour of ports from around the 1960's can be understood. Unfortunately, studies on these matters have generally proceeded only on

the basis of a descriptive account of the structure of port costs and underlying technology. Furthermore, economists have largely ignored the issue of productivity measurement. With the interest in applying new tools of analysis in production theory in industry studies in the 1960's and 1970's, it is surprising that economists were not attracted to study the process of introducing new types of capital equipment into the maritime industries. Perhaps the answer to this lies in the conclusions drawn by Bennathan and Walters (1979) that econometric investigation did not appear to be justified.

Nevertheless, the issue of port productivity has remained contentious, and it is common to make comparisons among ports. In the Australian context, the contribution of labour has been singled out for the greatest criticism. The prevailing view is that, despite the enormous investment in new capital equipment, labour inefficiencies are contributing to high costs in ports. Although it is often said that ports have become capital-intensive, the reality is that labour costs remain high. Satisfactory explanations of productivity differences need to be advanced, and this requires further consideration of the contribution that might be made on the subject by economic theory.

Chapter III examined several approaches which might be suitable for this purpose. The simplest method employs partial productivity measures and suffers serious theoret-

ical shortcomings. Though they are easily estimated, such measures are unable to comprehend production relationships in a satisfactory way. Experience in other parts of the transport sector have indicated that partial productivity measures provide biased estimates of productivity change. The co-existence of high rates of growth of output per man-hour and continuing claims of poor efficiency in ports raises similar doubts about the usefulness of partial measures. Despite these shortcomings, this approach has been widely employed, and is likely to continue to be used. The present study has aimed to indicate more satisfactory avenues for future research.

Acknowledging the need to adopt a total factor productivity approach, productivity differences have been associated with variations in output which cannot be explained by changes in the quantities of inputs. The neoclassical theory of production therefore associates productivity change with a shift in the production function. What is then required is a satisfactory representation of that function.

Two basic approaches have been investigated. The usual approach taken by economists is to employ econometric methods. Recent developments in the theory have provided more satisfactory tools of analysis and have justified the use of the cost function to represent the technology. Alternatively, index number methods which are consistent

with structural conditions can be employed. In practice, cost functions and productivity indexes have been estimated with some success in several areas of transport. The only published study which has reported the results of estimating a production function for a port has used a highly restrictive functional form, and there is little evidence of any success in applying new tools of analysis to study productivity in ports.

A possible reason for this is that econometric methods are not suitable in this area. Several economists have noted that data are invariably inadequate and that ports vary considerably, ruling out the possibility of cross-sectional studies. Furthermore, the changes over time have been too great to permit time-series analysis. Instead, it has been recommended that engineering production functions be estimated. Jansson and Shneerson (1982) have provided a recent example of this approach. However, it has been demonstrated that this approach, too, suffers serious shortcomings.

The use of engineering functions has validity where there exists a sound knowledge of the physical processes involved, a condition likely to be violated where there are significant labour inputs. This happens to be the case in ports, and the engineering studies have to be supported by strong assumptions about the need to combine labour in fixed proportion to other inputs. In any case, the approach makes

the unlikely assumption that the cost of ships' time should be included as an input into a port production process. In most cases, this is an unrealistic definition of the port.

On further reflection, port productivity studies can proceed on one of three bases. In the first place, the relevant unit of analysis is the port authority. A second approach is to examine the problem of managing a single berth or a terminal. The third approach examines the port taken as a whole, and requires aggregation over several actors in the port. All three approaches are capable of yielding relevant conclusions for policy analysis.

Studies of port authority performance have relevance to questions of administration, particularly for the smaller ports. On closer examination, it seems that it is possible to specify a variable cost function, although it requires detailed information on port authority expenditure. In practice, such data are likely to be difficult to obtain. Similarly, it is possible to specify a variable cost function for individual container terminals, but data limitations are likely to prevent empirical investigations. Firstly, data on costs and labour input are rarely reported at the level of the individual terminal. Secondly, if a large cross-section is required, Australian terminals would have to be compared directly with overseas container terminals.

Although studies at these levels are likely to be difficult to implement, it is desirable that published data be progressively improved. The third type of study requires aggregation over several entities that are collectively responsible for transferring cargoes and servicing ships. A suitable specification for estimating a variable cost function for a port has been discussed in Chapter VII. Furthermore, a group of similar ports has been identified as a basis for developing a set of pooled data upon which econometric investigation can proceed.

This specification requires the collection of data which are not currently published. However, the prospects for pursuing this approach appear to be reasonable. Co-operation would need to be gained from the individual port authorities to provide detailed information on labour input and maintenance expenditure. This goes beyond the resources of the present study. In conclusion, though, a promising basis for further study has been indicated. Given the paucity of work on this important subject, it is essential that greater resources be devoted to this topic in the future.

GLOSSARY

ANL: Australian National Line, the operating name of the Australian Shipping Commission

BERTH: Wharf space designated for use by a vessel, including adjacent working space

BREAK BULK: Conventional method of handling cargo whereby consolidated loads are broken down into individual shipments for final delivery to the consignee

BULK CARRIER: A vessel designed to carry dry cargo in bulk

BUNKER: The space on a vessel used for storing fuel; 'bunkers' refers to the fuel itself

CONFERENCE: A group of shipowners who have formed a cartel and who offer liner shipping services among a nominated set of ports on a regular basis

CONSERVANCY: Maintenance of channels, etc.

CONTAINER FREIGHT STATION: Depot operated by a carrier or a forwarder for the packing and unpacking of containers for less than full container load shipments; not necessarily in the port area, or even near the port (hence INLAND CONTAINER TERMINAL); also known as CONTAINER DEPOT, FREIGHT BASE

DEADWEIGHT TONNAGE (DWT): The weight in tonnes that a vessel can carry when fully laden

DUNNAGE: Material used for stowage of cargo on board the ship (packing, separation, etc.)

GROSS REGISTER TONNAGE (GRT): A measure of the total space of a vessel in terms of 100 cubic feet (equivalent tons) including mid-deck, between deck, and closed-in spaces above the upper deck, less certain exemptions

INLAND CONTAINER TERMINAL: See CONTAINER FREIGHT STATION

ISO: International Standards Organisation which, among its responsibilities, specifies standards for containers; for example, the standard TWENTY FOOT EQUIVALENT UNIT (TEU) is 6.1 metres (20 feet) in length, 2.44 metres (8 feet) wide, and 2.6 metres (8 feet and 6 inches) high

LASH: Lighter aboard vessel, a barge-carrying vessel

LINERS: See CONFERENCES

LO-LO: Lift-on-lift-off, another name given to container vessels where there is reliance upon shore-based equipment to load and unload the vessel

NET REGISTER TONNAGE (NRT): GRT minus the spaces that are occupied by machinery, bunkers, ballast and crew quarters

PALLET: A cargo tray designed to be moved by forklifts

PORTAINER CRANE: A crane designed for the loading and unloading of containers from cellular vessels

ROLL-ON-ROLL-OFF (RO-RO): A vessel designed to accommodate cargo on wheeled trailers moving on and off across ramps

STEVEDORE: Labour employed to load and unload cargo. The term is often also used to refer to the organiser of this labour. It is also common practice for stevedores to be used only for shipboard operations, with wharf labourers performing the land-side operations

TANKER: A vessel specially constructed and fitted for the carriage of liquid cargoes in bulk

TERMINAL: Berths and adjacent area used by a shipping operator(s) on a regular basis, encompassing storage and loading facilities, administration, etc

TRAMP: Vessel operating on a charter basis (time or voyage), and plying no fixed route and not adhering to a published schedule

TRANSHIPMENT: Transfer of cargoes from one ship for carriage on another

TRANSIT SHED: A shed in the port area, usually in the customs bonded area, which is positioned behind the berth to receive cargo unloaded from vessel for loading

TWENTY FOOT EQUIVALENT UNIT (TEU): The equivalent of a twenty-foot ISO container; standard used to equate units of varying dimensions; see also ISO

WHARFAGE: Charges levied on goods passing over the wharves by the port authority

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