The development of a production function for a container terminal in the port of Melbourne

R A Reker

Transport Planning Officer
Port of Melbourne Authority

D Connell

Transport Operations and Research Manager
Port of Melbourne Authority

D I Ross

Port Statistician
Port of Melbourne Authority

Abstract:

It is generally accepted that for Australia to be competitive on world markets it must become more productive. As a trading nation it is dependent on a reliable transportation system in which container terminals are a vital link for the shipment of goods and commodities. The waterfront in particular has been criticised for disadvantaging local exporters because of inefficiencies, an accusation that is all the more significant because of the large percentage of cargo that is carried by sea. In order to find ways of increasing port productivity it is essential that it can be suitably measured. This paper is the study of an attempt to develop a production function for a container terminal in the Port of Melbourne as an alternative performance indicator to partial factor productivity measurement

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Contact author:
Rudy Reker
Port of Melbourne Authority
World Trade Centre
Melbourne Vic 3005
Telephone: (03) 611 1895 Fax: (03) 629 8121

Introduction

As one element of its strategy to eliminate waterfront related transport impediments to Australia's trade, the Interstate Commission in its recent report (1989) recommended the development of national performance indicators and statistics.

Two aims of this strategy are to:

1. To increase the transparency and accountability of the waterfront industry giving waterfront users better information for decision-making, and

2. To enable the government to monitor the performance of monopolies or near monopolies in the industry.

UNCTAD (1987) supports the need to measure performance but adds that studies and reports carried out on port performance and productivity have overall been unsatisfactory. It goes on to say that any effort to analyse port performance is formidable because of a combination of the following factors:

(a) The sheer number of parameters involved;

(b) The lack of up-to-date, factual and reliable data, collected in an acceptable manner and available for publication or divulgation;

(c) The profound influence of local factors on the data obtained;

(d) The divergent interpretations given by various interests to identical results.

This paper does not argue the need for performance indicators. That issue was addressed by UNCTAD in 1976 and has been generally accepted as a necessary measure. The analysis presented here builds on the work of Hooper arguing the need for performance indicators that are rigorous and theoretically sound. Like Hooper we discount the use of simple ratios of output to input (partial factor productivity) as useful measures of productivity in favour of applying the theory of production to the transport industry.

The Theory of Production

A production function on which this theory is based is the broad relationship between a set of inputs and the quantity of output of a firm. It is an indication of the maximum output that can be achieved from each possible combination of a set of inputs based on their respective costs and a given budget.

If the data used is an appropriate reflection of the technology of the firm, it can for instance help to identify changes in output that occur as a result of substitution or complementarity i.e. a change in levels of input or combinations of input. It should also be possible to identify increases in output that are attributable to economies of scale or scope (Hooper 1984).

When dealing with only two factors of input (independent variables) and one output, (dependent variable) the function can be represented graphically or mathematically. However, when exceeding three variables it is no longer possible to portray the relationship graphically so that the only option is to express it as a mathematical equation.

The benefit of a production function is highlighted by a simple example. Much of the criticism levelled at Australia's container ports is substantiated by the argument that, compared with leading overseas ports, crane throughput here is extremely poor. However it would be futile to double crane performance if a terminal's storage capacity is not capable of handling the increasing volume of cargo. The performance of individual elements needs to be considered in the context of all elements. This approach should give a true indication of productivity increase (or decrease) due to a number of causes.

Purpose of this paper

This paper is the study of an attempt to develop a production function for a container terminal in the Port of Melbourne. If successful it would enable terminal managers to measure the performance of their operations based on the interaction of a number of relevant factors of a terminal simultaneously, in contrast to the current practice of looking at key elements individually.

The approach taken is such that it hopes to make terminal operators feel comfortable with this type of analysis and encourage them to either develop their personal skills and expertise in this field or employ the services of those that can assist them to achieve productivity gains using this method.

The "Terminal" selected for analysis

According to Hooper (1985b) there are "three bases on which Port productivity studies can proceed". The first examines the performance of the Port Authority itself. This option has been rejected though for two main reasons. Firstly, because it is only the second year that the Authority has been on a general ledger system of accounting and financial data, which is a vital factor in measuring productivity is difficult to extract from port records. Secondly, it is doubtful whether such data, which includes port charges, would properly reflect port performance.

The second base on which productivity studies can proceed is to examine the performance of a selected berth, terminal or stevedoring company. In view of the interest in waterfront reform at the present time, research in this area would be a preferred option. However, again it is difficult to obtain suitable data for analysis but for reasons other than those mentioned above. With a few notable exceptions most of the terminals approached refused to provide information because they maintain that it is commercially sensitive. This may be a misconception on their part though, because container rates, which they seek to protect, can easily be obtained through informal sources externally.

The third option for developing a function is to measure the overall performance of a port which, for the same reason again, cannot be considered because of the lack of reliable data. Various reasons are suggested for studying any one of these options but Hoopers conclusion is that the most promising choice theoretically is to analyse the Port as a whole.

Unable to proceed on the basis of any of the options recommended by Hooper, the only means of collecting sufficient reliable data to proceed with this study was to analyse three terminals as if they were one. This approach is considered to be acceptable for a number of reasons.

Firstly, the three terminals have the same geographical advantages and constraints because they are located side by side and share a common wharf comprising four berths. They also share a common access road and although the internal layouts are not identical, their operations can be regarded as similar.

Secondly, the equipment utilised is similar in as much as the terminals share the five container cranes owned by the Port Authority and although one operator utilises forklifts instead of straddle carriers, this is not considered to be a factor significant enough to preclude analysis. Finally, this approach maintains the confidentiality of what is considered to be commercially sensitive data.

The approach taken

A production function was selected in preference to a cost function after the approach of De Neufville and Tsunokawa (1981). In their study of five major east coast ports in the United States, they rejected the usual approach of cost function analysis because of the unavailability of reliable data on output and prices on factors of input which are necessary for this method of analysis. Instead they chose to estimate a production function, because contrary to that which applies in most other economic sectors, there is more data available on quantities, than on cost and prices in the shipping sector.

Although various user friendly statistical packages are available it was decided to carry out the estimation using the type of regression function which is standard on most spreadsheet packages, such as Lotus. Although the package used does not have the capacity to perform advanced statistical analysis it is suitable to determine the best line of fit of a set of data in the first instance. It is also easy to use and provides a straight forward approach for measuring multi factor productivity.

Data

For regression Wonnacott and Wonnacott (1977) recommend the use of as many independent variables as possible that may influence the dependent variable (see Appendix 1). This is to minimise the stochastic or random error and to eliminate the bias that may occur if an influential variable is inadvertently omitted.

Equally as important as having data that is representative of terminal operations, is the need to ensure that it is reliable. As stated earlier, some difficulty was encountered getting information on man-hours worked from terminal operators so that all the data ultimately used was extracted from the Port Authority's Research Department. This did limit the period covered by the data but because all the data used was derived from internal sources the problem encountered by De Neufville et al (1981) of obtaining conflicting information from otherwise reliable sources was minimised.

In view of the considerable work carried out on partial factor productivity by various Authorities in recent times, it was decided to first consider the suitability of their indicators both as individual performance measures and for use as factors of input (independent variables) for the production function in an effort to achieve some form of continuity. This exercise evolved into a completely separate study, the results of which are the "Recommended Measures" shown in Apppendix 2. However as stated already, access to data is a problem so that the factors finally used (see Appendix 2 also) were selected because of their availability, and reliability and as far as possible their compatibility with the recommended indicators. Although it is recognised the input factors are not totally independent, the degree of dependence was not within the scope of this paper and was assumed to be negligible.

As the measure of output (dependent variable) it was decided to use TEUs (Twenty Foot Equivalent (Container) Units). De Neufville et al (1981) and Chang (1978) both use tonnes for this purpose but only in default of not having access to suitable data on container numbers. The figures presented incorporate the number of 20 foot and 40 foot containers both full and empty. Some may argue that 20 foot and 40 foot containers should be separated because to regard 40 foot containers as two TEUs distorts the actual number of crane moves. This may have been a problem if the ratio of 20 foot to 40 foot units had changed significantly over the period surveyed, however that is not the case

Functional Analysis

Estimation of a function was initially attempted using multiple regression on the factors of input stated above with a view to estimating a Cobb-Douglas function once suitable indicators of capital and labour were identified. Before proceeding with the regression it was necessary to apply a logarithmic transformation to the original function to yield a function which is a linear function of the parameters. Although the R squared correlation coefficient was encouraging, the standard error of the individual parameters indicated that only the net operating time of the crane had any significant influence on the dependent variable. All possible combinations of the independent variables were tried but only in one instance was it possible to achieve a marginally better fit of the data. This occurred when net operating time was combined with the factors, hours at berth and the number of gangs, which raised R squared to 0.66

The form of the function was:

$$Y = 47.14\ C^{0.87}\ B^{-0.07}\ L^{0.04}$$

where C = net crane operating time
B = berth hours
L = gangs

In view of the fact that the labour variable "gangs" limited the scope of the data it was decided to expand the data set by regressing all the data, this time without the restricting variable "gangs". The R squared factor of the analysis rose to .85 overall but once again this was primarily due to the nett operating time of the crane.

The contribution of the other factors was not sufficient to warrant consideration as components of terminal operations which have any bearing on terminal productivity measurement

Discussion and conclusions

Two conclusions can be drawn from this analysis. Firstly it confirms the UNCTAD Monograph (1987) statement that data currently available is unsuitable for the measurement of terminal performance. It is fundamental to estimating either a cost or production function and in turn to examine productivity growth economies of scale and technical change. De Neufville et al (1981) confirmed this shortcoming, but still managed to estimate a functional form although their assumption that "berth length" and "number of cranes" are proxies for all inputs is debatable. Besides this, the indicators they used were not suitable for the terminal analysed in this paper because they contribute very little to the explanation of production in this case. Analysis clearly shows that labour (net crane hours) was the major explanatory factor of the production function. This is interesting in view of the large sums of money spent by container terminals on capital improvements in order to enhance efficiency

The second conclusion that can be drawn from this study, is that analysis should ideally be carried out for a terminal that has evolved in an operational sense. That is to say, where changes have been made over time to factors such as the length or number of berths, the number of cranes, the terminal layout, the number of container slots and the number of gates and lanes. This helps to determine the effect that a change to the characteristics of a terminal has on productivity particularly if factors are varied individually.

References

Association of Australian Port and Marine Authorities (1982), Collection and Publication of Statistics: A Guide for Australian Port Authorities, Melbourne, AAPMA

Australian Interstate Commission (1989), *Waterfront Investigation, Conclusions and Recommendations*, Canberra, AGPS

Chang, S (1978) "Production Function, Productivities and Capacity Utilisation in the Port of Mobile", *Maritime Policy and Management*, Vol.5, pp297-305

De Neufville, R and Tsunokawa, K (1981) "Productivity and Returns to Scale of Container Ports", *Maritime Policy and Management*, Vol.8, No.2, pp121-129

Hooper, P G (1984) *Productivity measurement in transport*, Melbourne, Ministry of Transport

Hooper, P G (1985b) *An essay on the measurement of productivity in ports*, Thesis, Faculty of Economics, University of Tasmania

National Research Council (1986) *Improving Productivity in US Marine Container Terminals*, Washington, National Academy Press

Thomas, R L (1985) *Introductory econometrics: theory and applications*, London, Longman

UNCTAD (1976), Port Performance Indicators, Geneva, United Nations

UNCTAD (1987) "Measuring and Evaluating Port Performance and Statistics", *Monographs on Port Management*, Vol.6, Geneva, United Nations

Wannacott, T H and Wannacott, R J (1977) *Introductory statistics for business and schools*, Toronto, Wiley

DATA USED FOR REGRESSION

DATE	DEPENDENT VARIABLE TEUs/MTH	SLOTS	TERMINAL AREA	NO. OF CRANES	TUEs HANDLED PER MTH	NET HRS	NO. OF BERTHS	GANGS	BERTH HOURS
		INDEPENDENT VARIABLES							
MAY'84	15581	3860	27.5	5	16757	1372.15	4	147	2128.5
JUNE	12292	3860	27.5	5	12699	870.6	4	75	1191.8
JULY	13304	3860	27.5	5	78748	948.55	4	97	1257.4
AUG	17451	3860	27.5	5	13645	1254.8	4	193	1509.3
SEPT	16731	3860	27.5	5	16118	1105.5	4	204	1224.1
OCT	14912	3860	27.5	5	14059	1017.3	4	115	1177.2
NOV	14119	3860	27.5	5	15637	1041.85	4	121	1246.0
DEC	13910	3860	27.5	5	15219	1099.35	4	108	1439.6
JAN'85	13999	3860	27.5	5	12701	941.85	4	134	1396.5
FEB	13826	3860	27.5	5	14399	1081.2	4	94	1227.4
MAR	16832	3860	27.5	5	17216	1349.7	4	155	2084.7
APR	13300	3860	27.5	5	13913	1007.05	4	95	1378.7
MAY	14511	3860	27.5	5	16541	1234.15	4	101	1578.2
JUNE	13840	3860	27.5	5	13204	955.95	4	95	1153.2
JULY	14397	3860	27.5	5	15900	1202.6	4	116	1464.7
AUG	18978	3860	27.5	5	18503	1341.95	4	139	1433.7
SEPT	13953	3860	27.5	5	13661	962.25	4	80	1260.9
OCT	13486	3860	27.5	5	13834	952.5	4	99	1231.9
NOV	17624	3860	27.5	5	18276	1294.65	4	111	1438.2
DEC	15723	3860	27.5	5	15699	1087.2	4	97	1665.4
JAN'86	11670	3860	27.5	5	12277	837.7	4	97	998.9
FEB	16822	3860	27.5	5	17043	1116.5	4	106	1318.6
MAR	13300	3860	27.5	5	14020	951	4	69	1314.2
APR	15513	3860	27.5	5	16812	1194.4	4	130	1460.2
MAY	14525	3860	27.5	5	14930	1049.9	4	108	1379.1
JUNE	13223	3860	27.5	5	13435	1047.3	4	102	1348.4
JULY	16504	3860	27.5	5	17145	1332.7	4	96	1478.4
AUG	13583	3860	27.5	5	14445	1038.8	4	108	1266.2
SEPT	16982	3860	27.5	5	16822	1181.8	4	121	1380.2
OCT	18229	3860	27.5	5	17625	1173.8	4	140	1535.7
NOV	13583	3860	27.5	5	13840	935.4	4	95	1298.2
DEC	15362	3860	27.5	5	16042	1131.4	4	109	1428.7
JAN'87	14892	3860	27.5	5	13521	903.5	4	102	1331.3
FEB	14687	3860	27.5	4.4	14568	951	4	45	1213.1
MAR	17359	3860	27.5	4	18491	1318.5	4	127	1679.7

DATA USED FOR REGRESSION

DATE	DEPENDENT VARIABLE TEUs/MTH	INDEPENDENT VARIABLES SLOTS	TERMINAL AREA	NO OF CRANES	TUEs HANDLED PER MTH	NET HRS	NO OF BERTHS	GANGS	BERTH HOURS
APR	18791	3860	27.5	4	18310	1306.7	4	134	2036.0
MAY	17500	3860	27.5	4	19303	1413.4	4	123	1790.4
JUNE	18163	3860	27.5	4	16360	1153.7	4	116	1655.2
JULY	16866	3860	27.5	4	18300	1287	4	122	1655.5
AUG	21361	3860	27.5	4	20331	1374.7	4	144	1649.7
SEPT	15204	3860	27.5	4	16467	1158.2	4	118	1361.6
OCT	16847	3860	27.5	4	15941	1167.1	4	114	1611.8
NOV	16076	3860	27.5	4	15823	1163.4	4	152	1661.5
DEC	16567	3860	27.5	4	17396	1193.4	4	264	1692.0
JAN'88	15740	3860	27.5	4	15043	1049.2	4	94	1375.9
FEB	13235	3860	27.5	4	15294	1037.3	4	88	1263.8
MAR	18068	3860	27.5	4	17791	1171.2	4	104	1401.6
APR	14326	3860	27.5	4	15139	1077.8	4	67	1456.1
MAY	17837	3860	27.5	4	16843	1113.8	4	200	1468.6
JUNE	11710	3860	27.5	4	11653	338.8	4	135	1706.2
JULY	16901	3860	27.5	4	17240	1119.2	4	254	1705.2
AUG	14698	3860	27.5	4	14596	1121	4	117	1753.6
SEPT	17179	3860	27.5	4	19368	1474.7	4	124	1802.4
OCT	17121	3860	27.5	4	16156	1099.1	4	385	1551.1
NOV	16494	3860	27.5	4	16193	1093.2	4	111	1629.4
DEC	18980	3860	27.5	4.5	18557	1218	4	120	1618.3
JAN'89	16993	3860	27.5	5	18246	1149.5	4	88	1308.3
FEB	12093	3860	27.5	5	13069	919.9	4	100	1292.0
MAR	18796	3860	27.5	5	18788	1306.5	4	96	2023.2
APR	15959	3860	27.5	5	18183	1131.5	4	108	1520.1
MAY	18167	3860	27.5	5	18475	1238.4	4	95	1467.2
JUNE	18112	3860	27.5	5	18748	1186.7	4	103	1601.9
JULY	16644	3860	27.5	5	16674	1166.2	4	110	1572.4
AUG	19943	3860	27.5	5	20580	1373.3	4	145	1918.0
SEPT	16509	3860	27.5	5	19311	1343.6	4	145	1767.3
OCT	19069	3860	27.5	5	19078	1214.9	4	128	1795.1
NOV	18982	3860	27.5	5	21128	1369.5	4	128	1795.1
DEC	19607	3860	27.5	5	20680	1314.3	4	91	1552.8
JAN'90	17992	3860	27.5	5	18088	1115.73	4	107	1571.5
FEB	14804	3860	27.5	5	15723	983.84	4	98	1299.0

PARTIAL MEASURES OF PRODUCTIVITY (PERFORMANCE INDICATORS)

	LABOUR	CRANES	BERTHS	YARD	GATES	EQUIPMENT
UNCTAD	GANG OUTPUT: TONNES PER GANG OR MAN HR	CONTAINERS PER GROSS OR NET CRANE HR	BERTH THROUGHPUT: CONTAINERS PER HOUR			
NRC	GROSS LABOUR PRODUCTIVITY: <u>NUMBER OF MOVES</u> MAN HOURS	NET CRANE PROD: MOVES PER GROSS GANG HOUR MINUS DOWNTIME GROSS CRANE PROD: MOVE PER GROSS GANG HR	NET BERTH UTILIZATION: CONTAINER VESSEL SHIFTS WORKED PER YEAR PER CONTAINER BERTH	YARD THROUGHPUT: TEUS PER YEAR PER GROSS ACRE	NET GATE T'PUT: <u>CONTAINERS/HOUR</u> LANE GROSS GATE T'PUT: EQUIPMENT MOVE PER HOUR PER LANE	
AAPMA	LABOUR USAGE: <u>TONNES OR TEUS</u> TOTAL MAN HRS	GROSS CARGO RATE: TONNES OR TEUS PER GROSS OPERATING TIME	GROSS CARGO RATE: TONNES OR TEUS PER TOTAL BERTH TIME NET CARGO RATE: TONNES OR TEUS PER TOTAL SHIP WORKING TIME			
RECOMMENDED MEASURES	CONTAINERS PER MAN HOUR	CONTAINERS PER VESSEL TIME AT BERTH	CONTAINERS PER VESSEL TIME AT BERTH	TEU SLOTS PER METRE OF BERTH LENGTH	TRUCK TURNAROUND TIME PER NUMBER OF TRUCKS	CONTAINERS PER GROSS OPERATING TIME
MEASURES USED FOR REGRESSION	GANGS	1. NO. OF CRANES 2. NET HOURS OF OPERATION	1. BERTH HOURS 2. NO OF BERTHS	1. TEU SLOTS 2. TERMINAL AREA		