An analysis of container handling at Australian ports

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Abstract

The levels and rates of change over time in the unit cost of handling containers at Australian container ports is one of the economic issues that the National Port Strategy highlights. However, data on unit costs are often unavailable due to reasons of commercial confidentiality. In the absence of data on unit costs, this paper examines the relationship between output and the quantity of inputs used at five container ports in Australia (Adelaide, Brisbane, Fremantle, Melbourne, and Sydney). We report the results of estimation, from both a simple Cobb-Douglas function and an augmented time-dependent Cobb-Douglas function. Analysis of the time-dependent production function shows that there have been significant improvements in both labour productivity and total factor productivity during the sample period at each of the five ports. Increases in labour productivity over this period vary from 1.4% per annum at the Port of Adelaide to 6.0% per annum at the Port of Melbourne, while increases in total factor productivity range from 1.5% per annum at Port of Fremantle to 4.5% per annum at Port of Melbourne. We also find that all five of the container ports examined experience decreasing returns to scale.

1. Introduction

This paper has two main objectives. First, we report estimates of input elasticities of output using Cobb-Douglas production functions for stevedoring services at five container port terminals in Australia. Second, we provide preliminary estimates decomposing the change in average labour productivity at each of the container ports into changes due to varying the mix of inputs used (i.e. changes in capital intensity), and changes due to “other factors”.

Dowd and Leschine (1990) in their discussion of factors that limit labour and capital productivity at a port terminal listed a number of “other factors”—both physical and institutional—that are relevant but difficult to model quantitatively. In the physical category these include the port terminal area, shape and layout; the type and quality of equipment available; and the type and size of vessels visiting the port terminal. Amongst those in the institutional category are union work rules (for example timing and frequency of meal breaks for gangs), import/export mix, container size mix, and customs and security regulations. Changes in each of these can affect factor (labour and capital) productivity. The later parts of this paper attempt to assess how important this has been in the case of Australia’s container ports.

The paper is divided has seven sections including this introduction. Section 2 provides a brief review of literature. Section 3 discusses the data and reports results from a qualitative analysis of the data. Section 4 discusses the estimation of Cobb-Douglas production functions for each of the five container ports, and an “five ports” function based on aggregated data for all five ports. Section 5 reports estimates of time-dependent production functions. Section 6 use the results from Section 5 to calculate changes in total factor productivity using a decomposition of average labour productivity based on a technique from Kohli (2004). Section 7 makes some concluding remarks.

2. Literature review

Hooper (1985) argued that there are three bases for studies of port productivity. A study could, at the highest level, examine productivity of a port authority. At an intermediate level analysis could focus on the activities of a port. At the most disaggregated level a study could focus on an individual berth, terminal or stevedoring company.

Numerous analytical methods are used in the study of port productivity depending on the objectives of the study and the available data. These include:

- stochastic frontier analysis—Cullinane and Song (2003, 2006);
- data envelope analysis—Cullinane et al (2004, 2005), Tongzon (2001), Martinez-Budria et al (1999);
- methods that compare the optimum versus the actual port throughput over a specific time period—Talley (1988);
- the estimation of a port cost function—De Neufville and Tsunokawa (1981);
- the calculation of total factor productivity—Kim and Sachish (1986);
- the measurement of single factor productivity—De Monie (1987); and
- the calculation of cargo handling productivity at berth—Bendall and Stent (1987, 1988a, 1988b), Ashar (1997).

The concept of a frontier relates not to the average production or average cost, but the maximum possible production given a set of inputs or the minimum possible cost of a set of outputs. Stochastic frontier (SFA) methods measure efficiency by comparing actual production or cost to the production or cost frontier. Efficient ports operate close to the frontier, while inefficient ports operate below the production frontier or above the cost frontier. Under SFA the frontier has a probability distribution, while data envelope analysis (DEA) relies on linear programming and assumes a non-stochastic frontier. Of the set methods listed above these are the most complex, and usually require detailed cross-sectional data to estimate the frontier. Frontier-based methods were not considered for this work, as the available data were unsuitable for the study of production or cost frontiers.

In the Australian context, the Steering Committee on National Performance Monitoring of Government Trading Enterprises (1992) reports an analysis by the Queensland Government Statistician's Office of the economic performance of the Port of Brisbane Authority. The study estimated total factor productivity and the economic rate of return for the port authority for the period 1981–82 to 1990–91.

At the port level, literature on Australian container port efficiency has focused on comparisons between container port terminals with the aim of producing a league table ranking of container port terminals. Examples of this literature include Tongzon (2001), Australian Bureau of Industry Economics (1993, 1995), Productivity Commission (1993, 1995), and BITRE (2009). Tongzon (2001) used 1996 port data and applied data envelope analysis to provide an efficiency measurement for four Australian ports (Melbourne, Sydney, Brisbane and Fremantle) and twelve other international ports.

Bendall and Stent (1987, 1988a, 1988b) used cross-sectional data to study productivity differences in cargo-related operations between alternative ship types in liner trades. The study focussed on three ship types that visited the Port of Sydney between 1973 and 1976: cellular container, Roll on-Roll off and LASH (Lighter Aboard Ship). Their objective was to assess the different cargo handling methods using analysis of covariance between throughput and a set of qualitative (dummy variables) and quantitative factors. This study differs from Bendall and Stent in that its focus is on cellular container ships and limits the explanatory variables to proxies of capital and labour input.

Reker, Connell and Ross (1990) estimated a Cobb-Douglas production function for the port of Melbourne using data on three terminals at the port. They use TEUs as the measure of output. Their explanatory variables are net crane operating time, berth hours and "gangs"—an estimate of the number of people employed. Only the net crane operating time was statistically significant and goodness of fit for their preferred model was 0.66.

The work presented in this paper differs from much of the previous research in that it focuses specifically on estimating production functions for container terminal operations, and makes use of relatively long time series which are consistent across the five mainland capital city container ports.

3. Data

3.1. Background

The data analysed in this paper is quarterly performance data supplied by terminal operators and published in BITRE's *Waterline* series (e.g. BITRE 2011). Three different indicators of terminal efficiency are published in Waterline: The crane rate, the vessel working rate (referred to in this paper as the labour rate), and the ship rate. The crane rate is calculated by dividing the quarterly throughput by the number of hours of crane operation during the quarter, while the labour rate/vessel working rate uses the number of hours of labour as its denominator. The ship rate combines these two into a single indicator of overall efficiency.

While these indicators provide a useful way of tracking changes in waterfront productivity over time, the data that underpins them facilitates some more sophisticated analyses. In this paper we attempt to analyse stevedoring operations based on inputs and outputs using data on crane and labour hours and terminal throughput.

The study reported in this paper uses data provided by stevedoring companies on output and associated inputs at the following terminals: Swanson Dock and Webb Dock at the Port of Melbourne, Fisherman Island at the Port of Brisbane, Brotherson Dock at Port Botany in Sydney, the Adelaide container terminal at Outer Harbour/Pelican Point, and North Quay in the Inner Harbour at the Port of Fremantle.

The dataset used contains quarterly observations of terminal output and capital and labour inputs. Output is measured both as total twenty-foot equivalent unit (TEU) throughput and as the number of lifts performed[1]. TEU is a standardised unit which counts a 40 foot container as equivalent to two twenty foot containers. While TEU is generally accepted as better reflecting cargo volume, an unstandardised count of lifts was thought to be a more appropriate measure of stevedoring output. The difference between the two is investigated in the next section.

The labour input variable is the net hours of labour utilised. This is calculated by dividing throughput (either in TEU or lifts) by the vessel working rate. It excludes time where work could not occur for a variety of operational and non-operational reasons such as adverse weather, delays caused by a vessel or its agent, cranes booming up for passing vessels, and others. Capital input is net hours of crane utilisation calculated in the same way as labour hours, and also excludes time where work could not occur for a variety of reasons. A full list of exclusions can be found in Waterline 50 (BITRE 2011, pp.28–31).

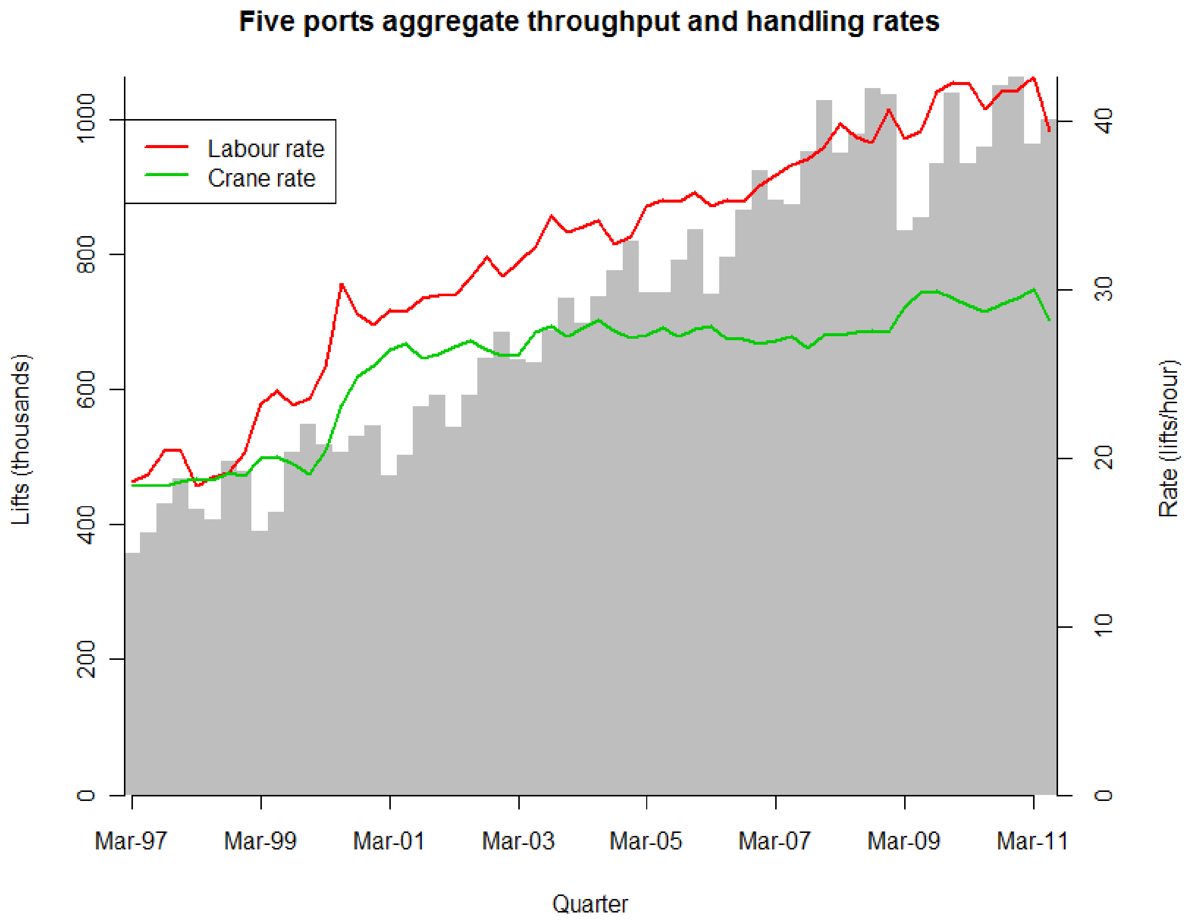
The dataset covers the period from 1997 quarter 1 to 2011 quarter 2 inclusive. Data do exist prior to 1997 but are not directly comparable to post-1997 data in all cases, and the series are incomplete for some ports. As such, these data were not considered for use.

3.2. Qualitative analysis

From 1997 to 2010 annual container throughput at Australia's five mainland capital city ports increased by two and a half times, or at an average annualised rate of 7.1 per cent. During this period, waterfront productivity as measured by the *Waterline* indicators also increased markedly from less than 20 lifts per hour in early 1997 to over 40 lifts per labour hour and just under 30 lifts per crane hour by the end of 2010. The most significant increases in productivity occurred around the turn of the century, coinciding with major waterfront industrial reforms. From 2001 until the onset of the global financial crisis output per labour hour continued to improve gradually, while output per crane hour remained almost unchanged throughout this period. Figure 1 illustrates this.

[1] This is the number of primary lifts only, i.e. lifts on or off a vessel at berth. Equivalently, it is the total throughput of the port measured in number of containers rather than TEU.

Figure 1: Five ports—Labour rate (vessel working rate) and net crane rate



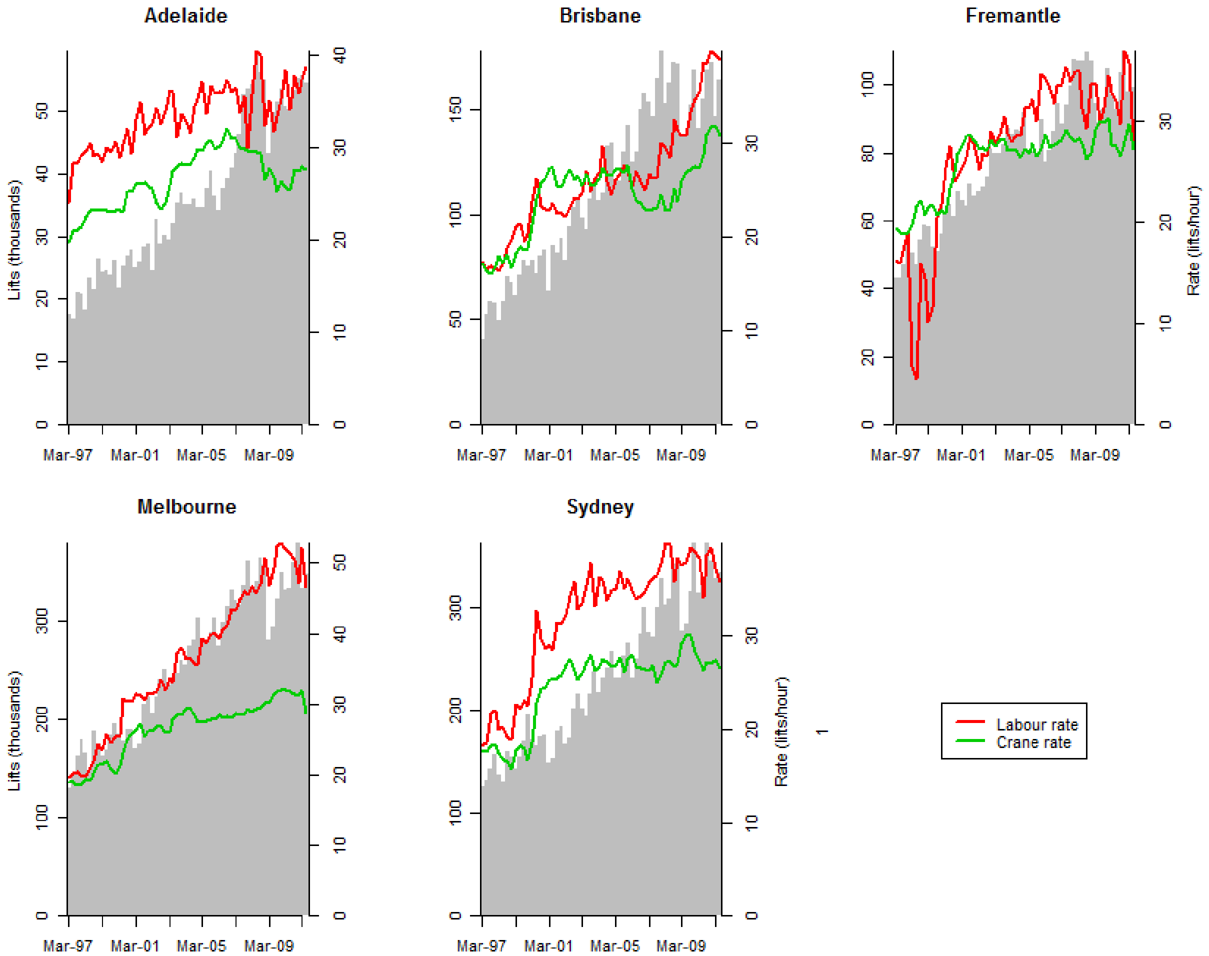
Although the data for individual ports exhibits higher variability, the patterns in the aggregate data are generally repeated as shown in Figure 2. The main exceptions are Adelaide which did not experience the same rapid increase in productivity around 2000 as the other ports did, and Melbourne which unlike the other ports continued to achieve modest improvements in crane rates post-2001. Additionally, crane and labour rates in Brisbane appear to have been affected by problems encountered during the implementation of new systems towards the end of the 2000s, but have since recovered strongly.

Looking at the relationship between output and both inputs at each of the ports, the strong relationships are immediately evident. Figures 3 and 4 plot the quarterly observations on a log-log scale, and allow differentiation between the five ports and three time periods.

It is clear that the relationship between crane hours and output is stronger than between labour hours and output. This is reinforced by correlation coefficients calculated on log-transformed variables, where lifts is found to be more highly correlated with crane hours (0.98) than with labour hours (0.92). However, these coefficients show that both inputs are very highly correlated with output.

It is also clear from these charts that the pre-2000 period (comprising 1997 quarter 1 to 2000 quarter 2 inclusive) was characterised by a different input–output relationship to the rest of the data. This difference is less pronounced in Adelaide than the other ports, but is still evident. The post-2009 period (quarter 1 of 2009 onwards) is less distinctive than the pre-2000 period but is still noticeably different, particularly for Brisbane and Melbourne.

Figure 2: Labour rate (vessel working rate) and net crane rate, by individual container port



To estimate elasticities of labour and capital (Sections 4 and 5) and in the subsequent analyses (Section 6), we restrict the data used to the period from 2000 quarter 3 to 2008 quarter 4 (a total of 34 observations per port). This ensures that periods of rapid change or upheaval which may result in misleading estimates are excluded from the calculations.

An interesting observation for Melbourne is that the labour rate has increased at a very similar rate to throughput. This has resulted in the labour input (in hours) remaining relatively stable for a significant period including that used to fit the models. Fremantle also exhibits a similar pattern, although labour input did increase slightly over the relevant period.

A potentially problematic property of these data which is not entirely surprising is that the two input variables are highly correlated with each other. Correlation coefficients for the log of labour hours with the log of crane hours range between 0.77 for Fremantle to 0.97 for Sydney. This causes issues when estimating regression models which include both inputs as explanatory variables. A further problem is that both inputs and output are strongly time-correlated for most ports. These issues are discussed in further detail below.

Figure 3: Quarterly lifts versus elapsed crane hours: 1997 March quarter to 2011 June quarter

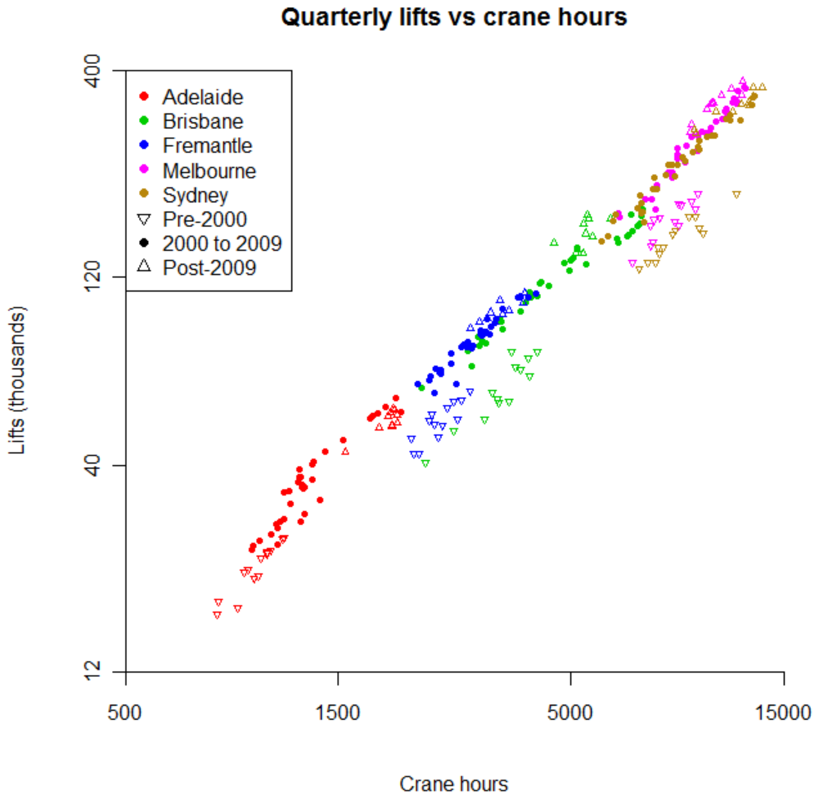
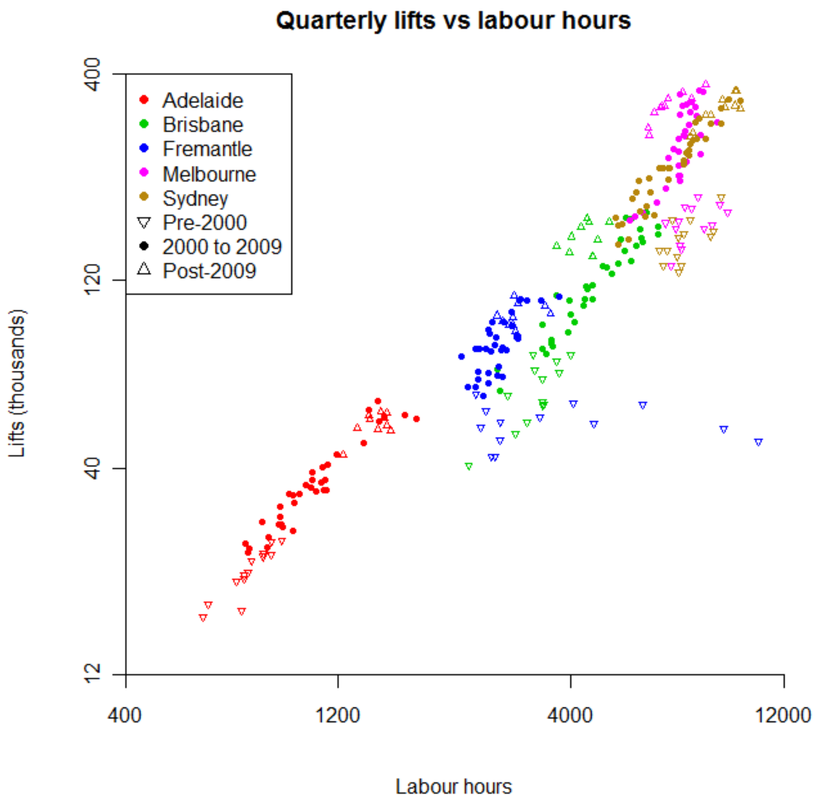


Figure 4: Quarterly lifts versus elapsed labour hours: 1997 March quarter to 2011 June quarter



4. Estimation of Cobb-Douglas production functions

The Cobb-Douglas production function is widely used in economics to represent the relationship of an output to inputs (factors of production). Among its advantages include simplicity of form and ease of estimation and interpretation of estimation results. Parameter estimates for a regression model associated with a simple Cobb–Douglas function are directly interpretable as output elasticities—they measure the responsiveness of output to a change in levels of either labour or capital used in production.

A strong criticism of the Cobb–Douglas is that it may require unrealistic assumptions regarding the underlying relationships. For example, Varian (1978, p.46) has shown that irrespective of what the “true” elasticity of substitution between capital and labour may be, the elasticity of substitution between capital and labour is –1 for a Cobb–Douglas function. Aware of these criticisms, other more complicated functional forms such as translog were investigated but did not produce superior results. A major constraint on model complexity encountered was the number of observations available compared to the number required to reliably estimate the parameters in each possible model.

The two factor Cobb–Douglas function has the following form:

(1) $$Q = \alpha K^{\beta_K} L^{\beta_L}$$

where:

Q is a variable representing output

K is a variable representing capital input

L is a variable representing labour input

β_K is a parameter representing the capital elasticity of output

β_L is a parameter representing the labour elasticity of output

α is a constant of proportionality

The parameters to be estimated are the elasticities of output with respect to capital and labour and the constant of proportionality (which is sometimes referred to as total factor productivity). These estimates are time-invariant and are calculated based on the data by taking the natural logarithm of both sides of Equation 1 and using simple linear regression on log-transformed input and output variables:

(2) $$\ln Q_t = \ln \alpha + \beta_K \ln K_t + \beta_L \ln L_t + \varepsilon_t$$

where quarterly observations are indexed in time by t and ε_t are residuals from the model fit.

A separate model was fit to the data for each port individually, and another on aggregated data for all five ports. For ports with multiple terminal operators the variables used were whole-port aggregates. To fit each of these models 34 observations in total were used, covering the period 2000 quarter 3 to 2008 quarter 4. The prior and subsequent observations were excluded due to the upheaval caused by the waterfront reforms and the onset of the global financial crisis respectively, and the likely impact on the usefulness of elasticity estimates that cover the periods in which they were occurring.

4.1. Estimation results

The model output is summarised in Table 1 (output measured as lifts) and Table 2 (output measured as TEUs). As the R^2 values for each model show, they all fit the data relatively well. However, these models have some noticeable weaknesses which are discussed below.

The constant in Equations 1 and 2 is often referred to as total factor productivity. This is defined by Comin (2006) as “the portion of output not explained by the amount of inputs used in production”. As such, it describes how effectively the inputs are used, and is determined by the level of technology and the efficiency of operational and management practices among many other factors. However, its value (presented here as $\ln\alpha$) is not directly interpretable.

The estimates of the elasticity of output with respect to capital are all statistically significant, have the correct sign and are of plausible magnitude. The estimates are greatest for Melbourne—the largest port by throughput and the port experiencing the strongest growth during the period—and smallest for Adelaide, which is the smallest port by throughput and experienced the lowest growth. This is true for both sets of models (those using lifts-based data and those using TEU-based data), and although the estimates vary slightly between the models they are broadly consistent with each other.

However, the estimates of the elasticity of output with respect to labour are problematic. In the case of the models using lifts-based data only the estimate for Adelaide is statistically significant, and the estimates for all but Adelaide and Brisbane have the wrong sign (although they are not significant). For the models using TEU-based data the story is worse, with the Fremantle model producing a negative and significant estimate for labour elasticity of output.

Table 1: Estimates for lifts-based 2 factor Cobb–Douglas production functions

Port	Model term	Estimate	Standard Error	P-value	Model R^2
Adelaide	Capital elasticity (β_K)	0.506	0.157	0.003	0.934
	Labour elasticity (β_L)	0.613	0.141	0.000	
	Constant (α)	2.598	0.404	0.000	
Brisbane	Capital elasticity (β_K)	0.771	0.081	0.000	0.977
	Labour elasticity (β_L)	0.128	0.125	* 0.316	
	Constant (α)	4.097	0.445	0.000	
Fremantle	Capital elasticity (β_K)	1.075	0.052	0.000	0.968
	Labour elasticity (β_L)	–0.159	0.078	* 0.050	
	Constant (α)	3.975	0.397	0.000	
Melbourne	Capital elasticity (β_K)	1.257	0.059	0.000	0.974
	Labour elasticity (β_L)	–0.185	0.114	* 0.113	
	Constant (α)	2.609	0.650	0.000	
Sydney	Capital elasticity (β_K)	1.238	0.119	0.000	0.978
	Labour elasticity (β_L)	–0.274	0.153	* 0.082	
	Constant (α)	3.529	0.385	0.000	
Five ports	Capital elasticity (β_K)	1.128	0.096	0.000	0.988
	Labour elasticity (β_L)	–0.115	0.160	* 0.477	
	Constant (α)	3.141	0.675	0.000	

* = not significant at 5% level
Note: Sample period 2000 September quarter to 2008 December quarter

These results must be interpreted with scepticism. Historically, savings in labour have contributed significantly to labour productivity at port terminals. For example, Gentle (1996) found that “By the end of the Waterfront Industry Reform Authority programme in October 1992, the stevedoring labour force had been reduced by 57 per cent. Labour force reductions and consequential improvement in labour productivity led to lower stevedoring costs.” (Gentle 1996, p301)

One possible explanation for these problems is co-linearity of the explanatory variables (inputs). There are two ways in which this can arise. The first is that the variables representing the inputs are redundant, with one explaining little or no variation in output that is not explained by the other. This was a possibility given the nature of the proxy for capital used, which more closely reflects the aggregate utilisation of capital rather than the level of capital investment[2]. Since utilising capital requires labour the two are likely to explain similar variations in output. The second is that another variable—here, time—is responsible for the co-linearity by virtue of its relationships with both existing explanatory variables.

In either case the co-linearity could be addressed by dropping one of the inputs. When single factor Cobb-Douglas functions were estimated for both labour and capital input separately, in each case the single elasticity estimate was positive and close to one. This demonstrates that co-linearity is indeed the cause of the problem, but does not produce results useful for further analysis. In an attempt to produce usable results we include time explicitly in the model. This is detailed in the following section.

Table 2: Estimates for TEU-based 2 factor Cobb–Douglas production functions

Port	Model term	Estimate	Standard Error	P-value	Model R^2
Adelaide	Capital elasticity (β_K) Labour elasticity (β_L) Constant (α)	0.572 0.613 2.388	0.489 0.190 0.171	0.005 0.001 0.000	0.916
Brisbane	Capital elasticity (β_K) Labour elasticity (β_L) Constant (α)	0.920 0.090 3.475	0.106 0.163 0.578	0.000 * 0.587 0.000	0.971
Fremantle	Capital elasticity (β_K) Labour elasticity (β_L) Constant (α)	1.262 –0.301 3.919	0.050 0.075 0.381	0.000 0.000 0.000	0.976
Melbourne	Capital elasticity (β_K) Labour elasticity (β_L) Constant (α)	1.449 –0.281 2.029	0.072 0.139 0.795	0.000 * 0.052 0.016	0.970
Sydney	Capital elasticity (β_K) Labour elasticity (β_L) Constant (α)	1.348 –0.267 2.815	0.146 0.187 0.473	0.000 * 0.165 0.000	0.964
Five ports	Capital elasticity (β_K) Labour elasticity (β_L) Constant (α)	1.271 –0.131 2.162	0.122 0.202 0.853	0.000 * 0.524 0.017	0.985

* = not significant at 5% level
Note: Sample period 2000 September quarter to 2008 December quarter

[2] Capital expenditure figures derived from annual reports are a possible alternative to the measure used. However these data are not available on a quarterly basis, are not necessarily consistent between ports, and may include significant capital expenditure unrelated to terminal operations.

5. Estimates of time-varying production functions

In this section we propose a modified Cobb-Douglas production function with the aim of producing more useful estimates of capital and labour elasticities than those presented in the previous section. Time is included explicitly in an attempt to prevent the co-linearity of the two inputs from producing unstable parameter estimates.

The functional form used is as follows:

(3) $$Q = \alpha K^{\beta_K} L^{\beta_L + \theta_L t} e^{\theta t}$$

where:

Q is a variable representing output

K is a variable representing capital input

L is a variable representing labour input

t is a variable representing time

β_K is a parameter representing the capital elasticity of output

β_L is a parameter representing the labour elasticity of output

θ is a parameter which describes the linear component of time trend (on log-output)

θ_L is a parameter which describes the interaction between labour input and time

α is a constant of proportionality

The five parameters of the function above are estimated from the data as previously by taking the natural logarithm of both sides of Equation 3 and using simple linear regression on log-transformed input and output variables:

(4) $$\ln Q_t = \ln \alpha + \beta_K \ln K_t + \beta_L \ln L_t + \theta_L t \ln L_t + \theta t + \varepsilon_t$$

where quarterly observations are indexed in time by t and ε_t are residuals from the model fit.

This functional form is a compromise between the Cobb–Douglas form (Equation 1) and the complexity of a translog-type function. The translog contains too many parameters to estimate from the number of observations used here. The inclusion of only a single interaction term (for labour input with time) was motivated by the initial qualitative analysis and the results of the time-independent modelling. Including the time–capital interaction term or a labour–capital interaction term resulted in unacceptably large standard errors.

Estimates for the modified Cobb-Douglas are summarised in Table 3. These are calculated using lifts-based data only, as the results from the previous models indicated that this data produced slightly better fitting models. This also agrees with the *a priori* view that the lifts measure better reflects output of stevedoring operations than TEU throughput.

Table 3 shows that the models fit very well, with R^2 statistics greater than 0.95 in all cases. Furthermore, all elasticity estimates are positive and most are statistically significant. The estimates of θ and θ_L are also relatively consistent in terms of magnitude and sign for the different ports.

Table 3: Estimates for time-dependent two factor production functions

Port	Model term	Estimate	Standard Error	P-value	Model R^2
Adelaide	Capital elasticity (β_K)	0.479	0.088	0.000	0.985
	Labour elasticity (β_L)	0.376	0.094	0.000	
	Time (θ)	0.049	0.022	0.033	
	Time × labour (θ_L)	–0.006	0.003	* 0.091	
	Constant (α)	4.286	0.721	0.000	
Brisbane	Capital elasticity (β_K)	0.550	0.130	0.000	0.986
	Labour elasticity (β_L)	0.401	0.124	0.003	
	Time (θ)	0.107	0.032	0.002	
	Time × labour (θ_L)	–0.012	0.004	0.004	
	Constant (α)	3.581	0.712	0.000	
Fremantle	Capital elasticity (β_K)	0.765	0.157	0.000	0.972
	Labour elasticity (β_L)	0.135	0.211	* 0.528	
	Time (θ)	0.035	0.045	* 0.438	
	Time × labour (θ_L)	–0.004	0.006	* 0.480	
	Constant (α)	4.068	1.073	0.001	
Melbourne	Capital elasticity (β_K)	0.421	0.104	0.000	0.993
	Labour elasticity (β_L)	0.432	0.104	0.000	
	Time (θ)	0.048	0.044	* 0.275	
	Time × labour (θ_L)	–0.004	0.005	* 0.401	
	Constant (α)	4.601	0.597	0.000	
Sydney	Capital elasticity (β_K)	0.831	0.102	0.000	0.991
	Labour elasticity (β_L)	0.016	0.123	* 0.898	
	Time (θ)	0.068	0.025	0.012	
	Time × labour (θ_L)	–0.007	0.003	0.023	
	Constant (α)	4.560	0.651	0.000	
Five ports	Capital elasticity (β_K)	0.577	0.118	0.000	0.995
	Labour elasticity (β_L)	0.415	0.130	0.003	
	Time (θ)	0.089	0.026	0.002	
	Time × labour (θ_L)	–0.008	0.003	0.003	
	Constant (α)	3.350	0.594	0.000	

* = not significant at 5% level
Note: Sample period 2000 September quarter to 2008 December quarter

5.1. Interpretation of results

The additional parameters introduced serve to complicate interpretation somewhat. Differentiating Equation 4 with respect to log-labour gives the following expression:

(5) $$\frac{\partial(\ln Q)}{\partial(\ln L)} = \beta_L + \theta_L t$$

This demonstrates that the change in output caused by changes in labour (i.e. the labour elasticity of output) is time dependent. If θ_L is positive labour elasticity is increasing with time, while if it is negative (as in all cases here) labour elasticity is decreasing with time. This in itself is not problematic, however being unable to include the corresponding time–capital interaction or a labour–capital interaction (due to the limited number of observations used) has some consequences. One of these is that the degree of homogeneity is also time-dependent.

A function $f(K, L)$ is homogenous of degree k if $f(\lambda K, \lambda L) = \lambda^k f(K, L)$ for all $\lambda > 0$. In other words, when each input is increased by a factor λ, output increases by some power k of λ. The degree of homogeneity k is estimated by the sum of the output elasticities with respect to each input. These estimates are shown in Table 5 for a point in time mid-way through the period for which data were used.

Table 5: Returns to scale with a time varying Cobb-Douglas function

Port	Degree of homogeneity (quarter 4, 2004)
Adelaide	0.747
Brisbane	0.734
Fremantle	0.827
Melbourne	0.781
Sydney	0.721
Five ports	0.848

These estimates suggest that stevedores at Australia's container ports faced decreasing returns to scale during the period studied—that is, the degree of homogeneity is less than 1. This is in broad agreement with Reker et al (1990) who estimated decreasing returns to scale for the port of Melbourne. Furthermore, the negative time-labour interaction implies that magnitude of returns to scale declined between 2000 and 2008, although the interaction term was not statistically significant in all models. The results may also be affected by the lack of capital–time interaction in the model, which (had there been sufficient data to estimate it precisely) may have been positive and thus balanced the effect of decreasing labour elasticity.

While this result is subject to the caveats and qualifications discussed above, it does suggest that expansions of terminal operations at these ports may have become more difficult to achieve during the period studied (i.e. a change in the quantity of inputs would have resulted in a larger change in output in 2000 than in 2008). The reasons for this change are not explored in this work, but one possibility relates to changes in the size mix of vessels over the period in question and the extent to which existing equipment is suited to handling them. This is not to say that expansion has become impossible, and a number of expansion projects recently undertaken attest to this. However, should the apparent trend continue a point will inevitably be reached where operational expansion is no longer viable. Further study is necessary to determine the validity of these results, and to investigate possible causes.

6. Decomposition of average labour productivity

Kohli (2004) in the context of national productivity uses a mathematical technique to decompose changes in average labour productivity into changes due to "changes in factor endowments" and changes due to other factors. Although at a national level this second category is often thought of as technological change, at the level of the firm it encompasses a wider range of effects. The ABS Business Characteristics Survey collects information on four separate categories of "innovation" by firms, namely:

- New or significantly improved goods and services;
- Operational process innovation: changes in "methods of producing or delivering goods and services";
- Organisational process innovation: changes in "strategies, structures or routines which aim to improve the performance of this business"; and

- Marketing methods innovation: changes in "design, promotion or sales method[s]" (ABS 2011, p.18).

Changes in productivity due to all of these types of innovation contribute to this second category. In addition, factors outside the control of the firm (such as the introduction or removal of government regulation) can also contribute to changes in productivity, and such changes also fall under the change attributed to other factors.

Kohli uses the average product of labour to define a labour productivity index:

(6) $$a_L(L, K, t) = \frac{f(L,K,t)}{L}$$

(7) $$A_{t,t-1} = \frac{a_L(L_t,K_t,t)}{a_L(L_{t-1},K_{t-1},t-1)}$$

The index values $A_{t,t-1}$ represent period-on-period changes in the average product of labour, which is calculated from the estimated production function. The decomposition of the labour productivity index is effected using two additional indexes, each of which is the geometric mean of a Laspeyres- and a Paasche-like index:

(8) $$A_{t,t-1} = A_{V,t,t-1}.A_{T,t,t-1}$$

(9) $$A_{V,t,t-1} = \sqrt{\frac{a_L(L_t,K_t,t-1)}{a_L(L_{t-1},K_{t-1},t-1)}.\frac{a_L(L_t,K_t,t)}{a_L(L_{t-1},K_{t-1},t)}}$$

(10) $$A_{T,t,t-1} = \sqrt{\frac{a_L(L_{t-1},K_{t-1},t)}{a_L(L_{t-1},K_{t-1},t-1)}.\frac{a_L(L_t,K_t,t)}{a_L(L_t,K_t,t-1)}}$$

Equation 10 also represents one definition of total factor productivity (Kohli 2004). The change attributed to the passage of time (as opposed to capital and labour inputs) provides the basis for the estimate of the change in total factor productivity. The other component related to the change in factor endowments represents the effect of changes in capital intensity (the ratio of capital input to labour input). Average labour productivity will exceed total factor productivity when capital deepening occurs (ibid.).

By explicitly including time in Equation 3, it is possible to use the estimates based the model fit (Table 3) to perform this decomposition. The results are presented in Table 6. While all five ports experienced growth in both labour and total factor productivity during the period, there are some noticeable differences between them.

Table 6: Labour productivity change decomposition, 2000 Q3 to 2008 Q4

Port	Annual change in average labour productivity	Change attributed to changing capital intensity	Annual change in total factor productivity
Adelaide	+1.44%	–2.47%	+4.01%
Brisbane	+3.56%	+1.26%	+2.27%
Fremantle	+3.33%	+1.87%	+1.43%
Melbourne	+6.00%	+1.43%	+4.51%
Sydney	+2.56%	–0.14%	+2.70%
Five ports	+3.97%	+1.21%	+2.73%

Note: The decomposition of changes in labour productivity is multiplicative (see Equation 8).

Labour productivity across all five ports increased by 4% per annum over the period. This is explained by an increase of 2.7% per annum in total factor productivity, and an increase of 1.2% per annum due to capital deepening. While Brisbane and Fremantle both experienced increases in labour productivity similar to the overall average, Fremantle's increase was driven more by capital deepening than by increases in total factor productivity.

Sydney experienced lower than average labour productivity growth, but this was due to capital intensity remaining stable—total factor productivity growth in Sydney was equal to the 5-port average during the period. Adelaide appears to have experienced relatively modest growth in labour productivity, however this is due to an apparent decline in capital intensity. Adelaide achieved the second-highest growth in total factor productivity over the period.

Melbourne is the stand-out performer, achieving growth in labour productivity of 6% per annum over the period, driven primarily by increases in total factor productivity of 4.5% per annum.

7. Conclusions

In this paper we present analyses of data on inputs and outputs of stevedoring for the period following the waterfront reforms to the onset of the global economic crisis. We find that during this period, stevedores at container terminals in Adelaide, Brisbane, Fremantle, Melbourne and Sydney achieved increases in both labour productivity of between 1.4% per annum and 6.0% per annum and increases in total factor productivity between 1.4% per annum and 4.5% per annum. Stevedoring operations became more capital intensive in general, although operations in Adelaide appear to have become less capital intensive and there was no change in capital intensity for Sydney. Stevedoring operations at all five ports were also found to have experienced decreasing returns to scale during this period.

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