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Impact of increasing container ship size on container handling productivity at Australian ports

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Abstract

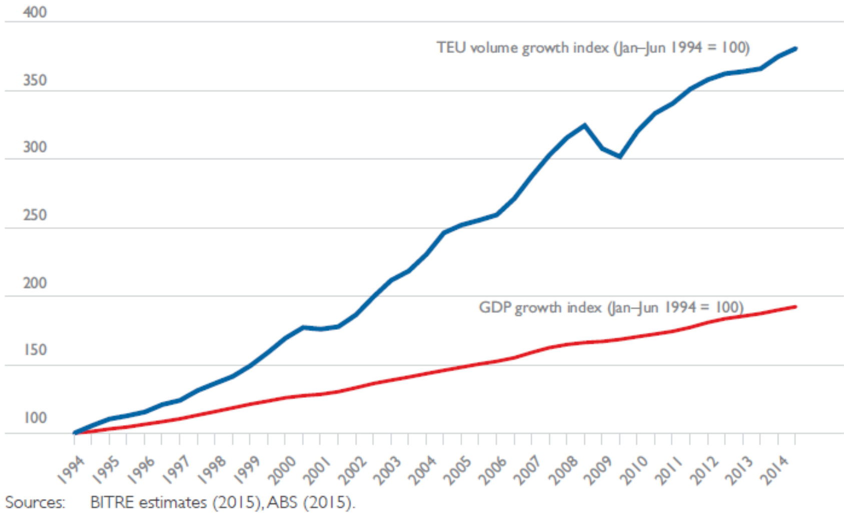
The size of container ships visiting Australia's ports has been increasing in recent years. This has important implications for operational optimisation and infrastructure planning in ports and associated areas. BITRE's *Waterline* series has published statistics on container port activity since the mid-1990s. This paper presents an initial analysis of these data at three of Australia's largest container ports: Melbourne, Sydney and Brisbane. We explore the nature and timing of increased visitation of very large vessels (>55,000 GT), before looking at the coincident effects of this on port productivity and efficiency. We analyse the recent time series of wharfside and landside indicators published in *Waterline*. Our results indicate that during 2013 semester 2 there was a sharp upturn in the number of very large vessels making their first call to Australia's major container ports. The TEU carrying capacity of very large vessels has resulted in fewer overall berth visits; yet strong and sustained growth in TEU exchange. Since 2013 semester 2, both wharfside and landside indicators of productivity and efficiency have declined at all three ports. In Sydney, the principal indicator of multi-factor productivity (ship rate, in TEUs per hour), has experienced a dramatic decline (-26.5%) when December 2014 results are compared to pre-2013 semester 2. Landside, container and truck turnaround times have increased from historical minimums achieved over 2010-2012 by 14.5-33.8% across the three ports, signalling reduced efficiency. We also examined slot utilisation for trucks transporting containers from and to ports, and show that while the number of slots has been increased to handle increased throughput, this mechanism alone has been insufficient to address concurrent decline in landside efficiency, particularly at Melbourne and Sydney.

While the timing of these declines in wharfside productivity and landside efficiency coincide with increased visitation by very large vessels, a broad range of factors may be contributing to these results. Improvements in wharfside productivity may not lift port performance if landside efficiency is not also addressed. Forecast growth in container throughput at Australia's ports is likely to manifest in increased frequency of visitation from very large vessels. To maintain or improve Australia's port performance in the face of this increased visitation, a terminal view of productivity and efficiency is critical in optimising operations, achieving supply chain integration, and guiding investment decision-making. This poses a significant challenge for port stakeholders and Government.

1. Introduction

Australia has five major container terminal ports: Brisbane, Sydney, Melbourne, Adelaide and Fremantle. Australia's container ports contribute significantly to the nation's domestic consumption and exports. Figure 1 shows the sustained, significant growth in total TEUs exchanged at Australia's container terminal ports over the last 20 years (BITRE, 2015). Notwithstanding the sharp dip associated with the Global Financial Crisis (GFC), circa 2008-09, this long-term growth has been higher than non-farm GDP growth over the same period. This growth in the number of TEUs exchanged at Australia's container ports forms the backdrop to this paper. The last 20 years has witnessed significant change in Australia's maritime industry, both at sea and in ports.

Figure 1: Growth in container traffic compared to GDP growth (Jan-Jun 1994=100). From BITRE (2015).



There has been a recent marked international increase in container ship size (UNCTAD, 2014). The theory of optimum ship size (Kendall, 1972) holds that the optimum size is one which minimises total transport costs. In practice this is a tradeoff between ship costs (which favour larger vessels to achieve economies of scale (Cullinane and Khanna, 2000)) and terminal costs (which are the 'main check on the growth of ship size' (Jansson and Shneerson, 1982, p. 217)). Various maritime authors have highlighted the potential challenges larger vessels pose for port and terminal infrastructure around the world. However, this is moderated in Australia's case; balancing the current upper limit on vessel size of around 9000 TEU at Australia's ports (due to draught limitations of around 14.5 m) is the status of Australia's shipping routes as largely 'feeders' within the South East Asian 'hub-and-spoke' network. Ng and Kee (2008) highlight that optimum vessel size may differ for 'feeder' and 'trunk' routes. This suggests that harbour bathymetry and major terminal infrastructure scaling at Australia's ports are unlikely to come under immediate pressure. However, Australia's, growth forecasts of container throughput are of the order of 5.1% *per annum*, more than doubling total throughput by 2033 (BITRE, 2014). For port infrastructure planners and operators, this presents future challenges for maintaining, and even improving container terminal efficiency and productivity, despite increased total volumes and vessel size.

This paper focuses on a nearer-term issue: we examine the time series of port performance indicators and the timing of increased very large vessel visitation.

2. Method

2.1 Hypotheses

Anecdotally, congestion in and around Australia's container ports is a frequently-raised issue in maritime circles[1] (IA and NTC, 2010; DIRD, 2014; Lubulwa et al., 2011). There are many factors influencing this, within and outside the terminal. This paper considers within-terminal performance indicators. Our working hypothesis asks: *'Is the timing of increased visitation from very large vessels associated with changes in performance indicators at Australia's container ports?* To address this hypothesis, we firstly seek evidence of an increase in vessel size visiting Australia's container ports. We also explore the relationship between vessel size

[1] See:
http://portcapacity.portofmelbourne.com/pages/past-present-future.asp
http://www.ceda.com.au/news-articles/2012/06/portsvic

and TEUs exchanged, before studying in detail the timing of first Australian port visit of vessels in the larger size classes.

2.2 Data Sources

BITRE has national stewardship of statistical collections relating to container port activity. These collections are based on voluntary data provision by port stakeholders to BITRE over many years. BITRE uses these data to calculate port performance indicators, and publishes these in its periodical report *Waterline* (BITRE, 2015), part of our maritime series. *Waterline* reports on trends in port activity at the five major Australian container terminals, and provides the latest indicators on: (a) throughput; (b) container handling productivity (wharfside) and efficiency (landside); and (c) the cost of importing and exporting containers. It covers both the loading/unloading of container ships and the transport of containers to/from terminals. This paper uses the time series of *Waterline* indicators and ship visits data provided by ports. The length and consistency of these time series is a valuable attribute for exploring emergent trends. Vessel visit data from 1996 through to the present was available for three ports: Melbourne, Sydney and Brisbane, so in this paper we have concentrated on these three ports, which are also the largest.

Waterline currently defines the following vessel sizes:

Small:	5,000 – 34,999 Gross Tonnage (GT)
Medium:	35,000 – 49,999 GT
Large:	50,000 – 55,000 GT

We define the 'Very Large' vessels in the Australian Context as > 55,000 GT.

2.3 Indicators

There is a substantial literature on measures of port productivity and efficiency (e.g. Frankel, 1991; Tongzon and Ganesalingam, 1994). In this paper, we take a practitioner, rather than academic perspective, and utilise the *Waterline* indicators for their value as a time series. These indicators are best understood as *partial* productivity and efficiency indicators (Bichou, 2006; BITRE, 2015). While acknowledging the significant influence of cost structures (e.g. tariffs) on port performance, this dimension is beyond the scope of this paper (though a priority for future work). To test our hypothesis, we used the following *Waterline* indicators in our analysis (with full methodological detail contained in BITRE (2015)):

2.3.1 Wharfside (measures of physical productivity (Bichou, 2006))

- **Crane rate** (TEUs/hour) (a proxy indicator of capital productivity). This is indicator 2.4 in *Waterline*.
- **Labour rate** (TEUs/hour) (a proxy indicator of labour productivity). This is indicator 2.5 in *Waterline*.
- **Ship rate** (TEUs/hour) (a proxy indicator of multi-factor productivity). This is indicator 2.6 in *Waterline*.

2.3.2 Landside (measures of technical efficiency (Bichou, 2006))

- **Average truck turnaround time** (min). This is indicator 2.10 in *Waterline*.
- **Average container turnaround time** (min). This is indicator 2.11 in *Waterline.*
- **Slot utilisation for trucks transporting containers from/to ports.** This is based on *Waterline* indicators 3.1-3.5, which look at the number of slots made available, and the number actually utilised.

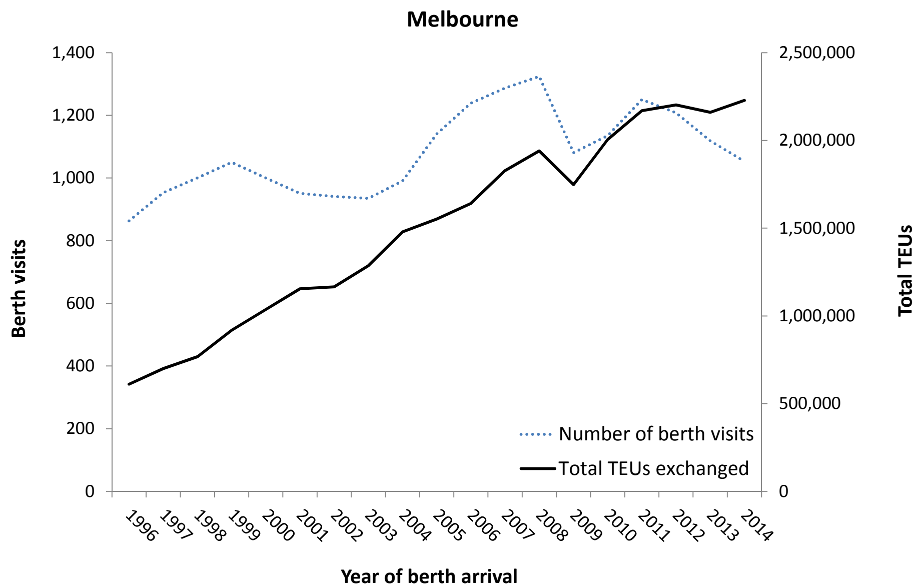
The slot utilisation data allow analysis of the time of day (day [peak], evening, night [collectively: off-peak]) and day of week that trucks access ports to receive or dispatch containers. This indicator is an imperfect proxy, because it does not include all truck movements from/to ports. A proportion of container movements is performed by bulk runs trucks; a proportion of containers is packed/unpacked directly at ports and involve no container movement *per se*; and finally, a proportion of containers is transported from/to ports via rail.

3 Results

3.1 Increasing vessel size

Figures 2-4 plot two time series for the individual ports of Melbourne, Sydney and Brisbane: number of berth visits and total TEUs exchanged. These figures consistently demonstrate that, following the severe dip of the GFC, total TEUs exchanged has resumed its long-run linear upwards trajectory. Since the pre-GFC peak, total TEUs exchanged have increased by 14.8% in Melbourne; 21.6% in Sydney; and 42.7% in Brisbane (Table 1). Yet, paradoxically, number of berth visits over the same period (since the pre-GFC peak) has *declined* at all three ports. Berth visits for the most current year (2014) are 20.5% lower than the pre-GFC peak for Melbourne; 12% lower for Sydney, and 7.8% lower in Brisbane (Table 1).

Figure 2: Number of berth visits and Total TEUs exchanged for Melbourne: 1996-2014.



This is explained by the increased TEU carrying capacity of visiting vessels – i.e. larger vessels, and is more directly demonstrated via times series of the mean and 95th percentile of vessels visiting these ports, shown in Figures 5-7. These allow us to identify a point in time where there was a sudden and dramatic increase in the largest vessel size class across these ports: the second semester of 2013. To confirm this, we interrogated the vessel visit database and plotted histograms of vessel size. We stratified the year and semester of first Australian port visit by each ship into two periods, pre- and post-semester 2, 2013. Figure 8 presents the results, and demonstrates that the median size of vessels introduced during and since 2013 semester 2 (55,000 GT), is significantly larger than the median vessel size for the former period (30,000 GT).

Figure 3: Number of berth visits and Total TEUs exchanged for Sydney: 1996-2014.

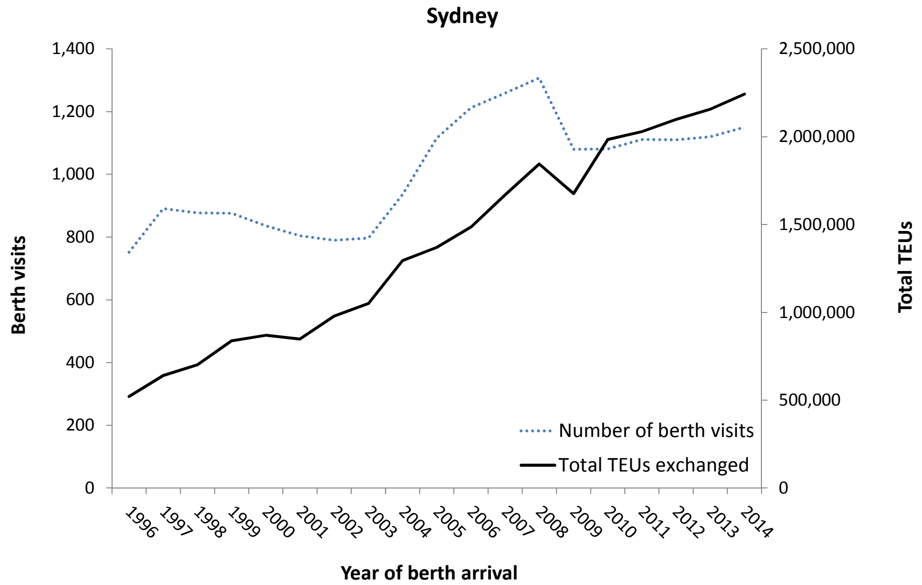


Figure 4: Number of berth visits and Total TEUs exchanged for Brisbane: 1996-2014.

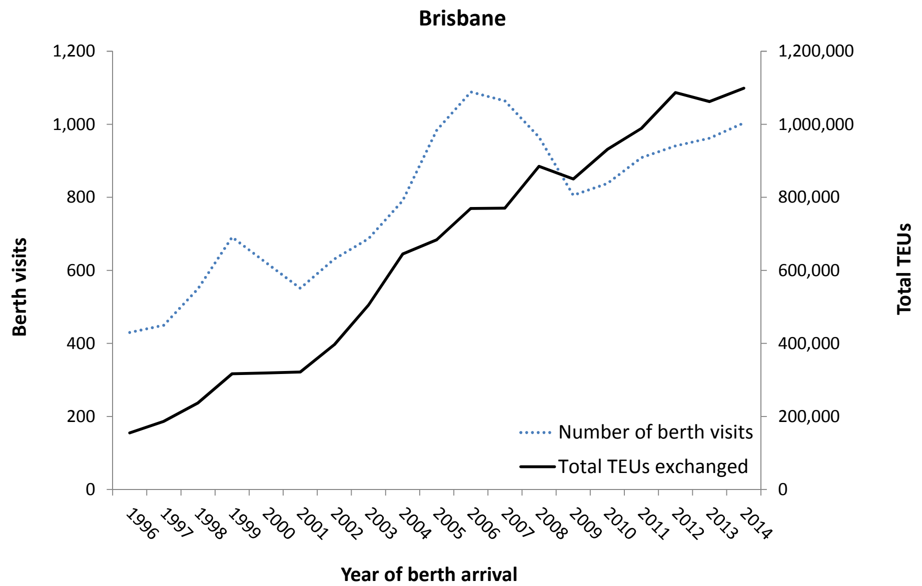


Table 1: Berth Visits and Number of TEUs exchanged at Ports Melbourne, Sydney and Brisbane.

Port:	Indicator:	Pre-GFC peak†:	2014:	% difference:
Melbourne	# Berth Visits:	1,324	1,053	-20.47%
	# TEUs exchanged:	1,939,734	2,227,539	14.84%
Sydney	# Berth Visits:	1,307	1,150	-12.01%
	# TEUs exchanged:	1,844,710	2,243,108	21.60%
Brisbane	# Berth Visits:	1,089	1,004	-7.81%
	# TEUs exchanged:	769,916	1,098,699	42.70%

† For berth visits in Melbourne and Sydney, the pre-GFC peak was 2008; for Brisbane, it was 2006.

Figure 5: Mean and 95th percentile of vessel size visiting Port of Melbourne: 2006-2014. Each year is incremented by quarters (e.g. 2013.1 = first quarter, CY 2013).

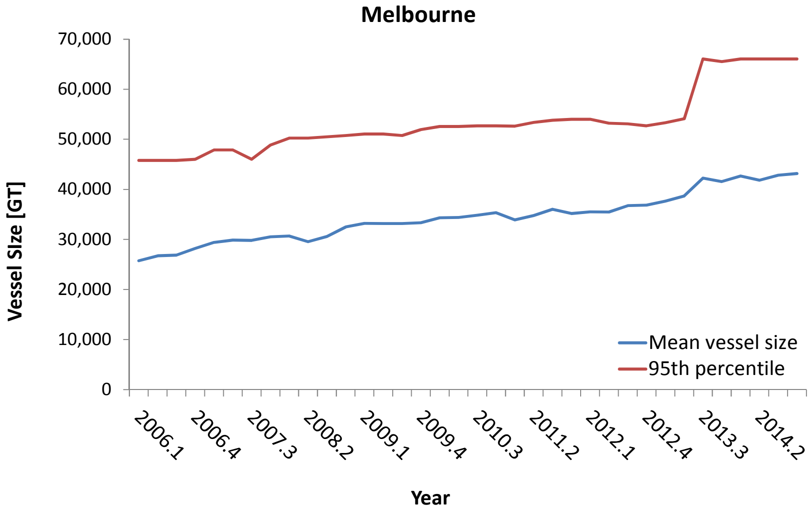


Figure 6: Mean and 95th percentile of vessel size visiting Port of Sydney: 2006-2014.

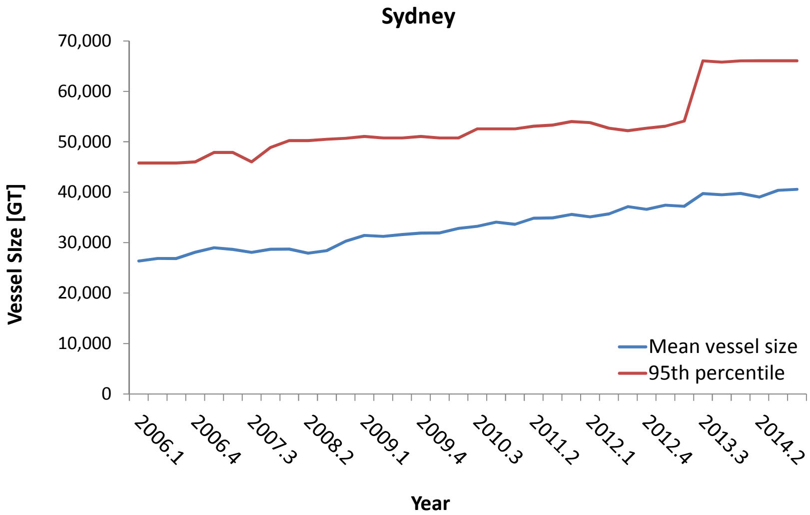


Figure 7: Mean and 95th percentile of vessel size visiting Port of Brisbane: 2006-2014.

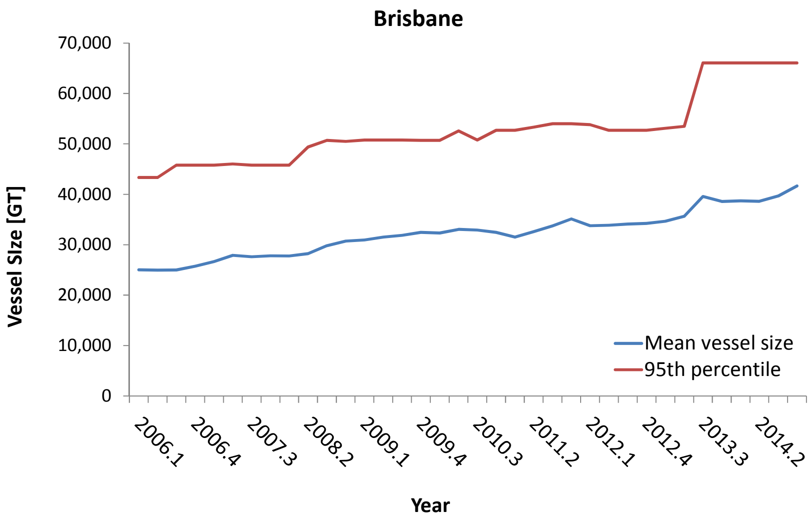


Figure 8: Histogram of vessel size, stratified by time period of first major Australian container port visit. Each year is incremented by two semesters (e.g. 2013.1 = 2013 first semester).

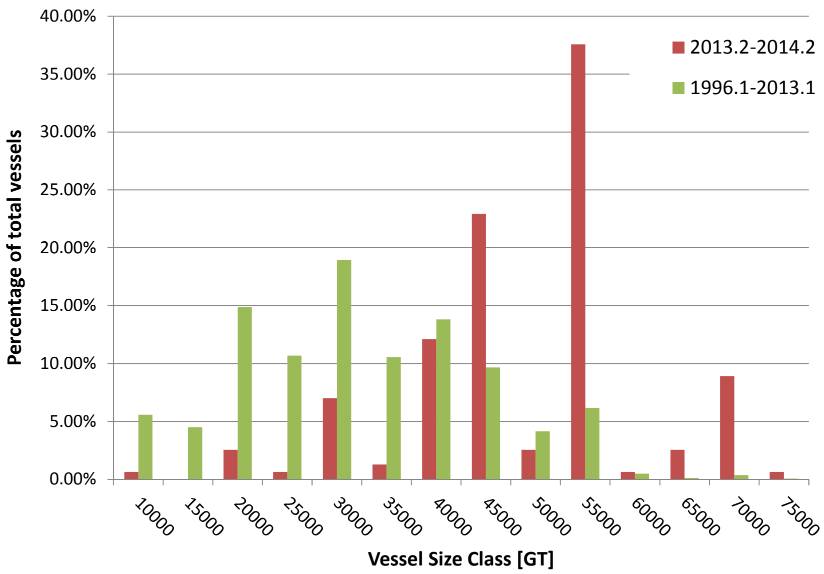


Figure 9: Histogram of vessel size, stratified by time period of first major Australian container. Each year is incremented by two semesters (e.g. 2013.1 = first semester 2013).

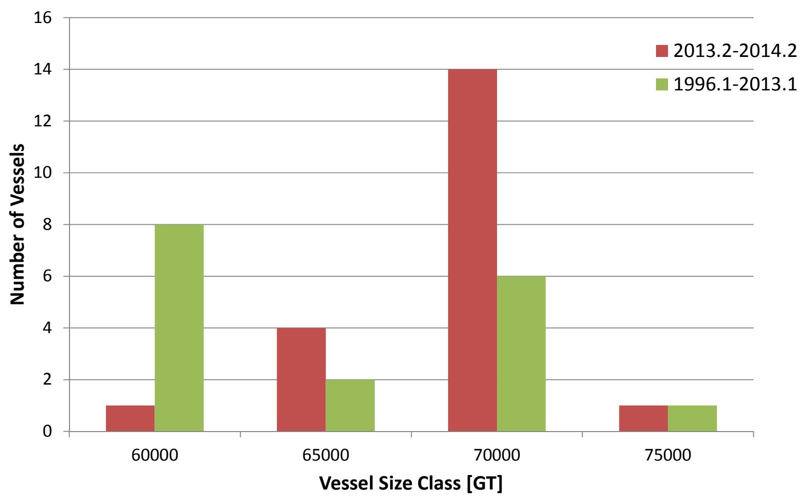


Figure 9 shows the histogram of very large vessel size classes (>55,000 GT), based on numbers of vessels. Figure 9 indicates that while over the entire 18-year period of 1996-2013, six vessels in the ≥65,000 - <70,000 GT size class first visited a major Australian container port (Melbourne, Sydney or Brisbane), in the 18-month period of 2013.2-2014.2, more than double this number of vessels in this size class (14) visited a major Australian container port for the first time. Figure 9 demonstrates both the suddenness and the order of magnitude of this 'very large vessel' phenomenon. Of the 157 unique vessels that first visited a major Australian container port over the 2013.2-2014.2 period, the 'very large' vessel size represented 20 vessels, or 12.7% of vessels making their first visit. At present, this is a relatively small number, and a small proportion. It is therefore important not to overstate the current 'very large vessel' phenomenon: it is still an emergent trend. However, the larger carrying capacity of these vessels is contributing to the strong growth in TEUs exchanged at these ports. Next we consider the time series of wharfside and landside indicators of port productivity and efficiency, and look at the timing coincidence of any changes in these indicators.

3.2 Wharfside Indicators

Figures 10-12 plot the time series for labour rate, crane rate and ship rate, for each of Ports Melbourne, Sydney and Brisbane. Superimposed on these graphs is a black line denoting the 2013 semester 2 change point identified in Section 3.1, after which very large vessel visitation has become more frequent at these ports. Labour and ship rates exhibit the strongest volatility of the three indicators. While crane rate was the most stable of the indicators, it also represents the lowest rate in TEUs/hour.

Figure 10: Time series of wharfside productivity indicators for Port of Melbourne.

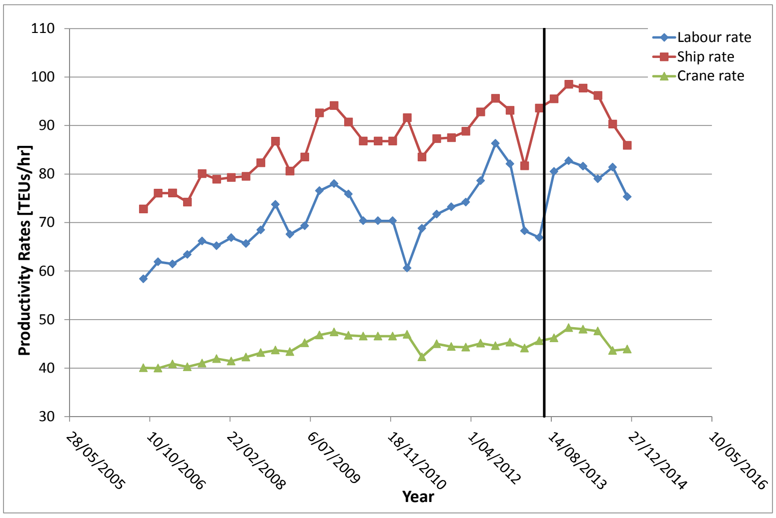
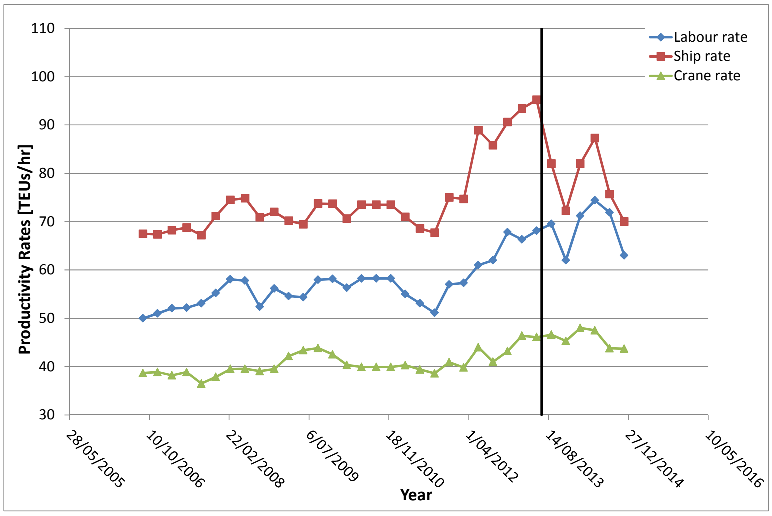
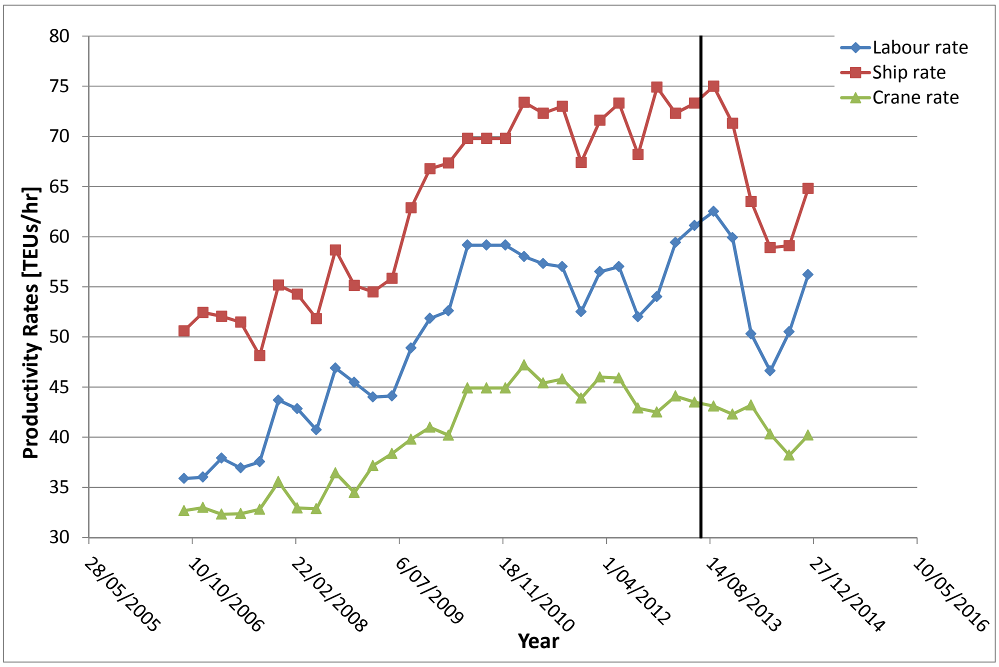


Figure 11: Time series of wharfside productivity indicators for Port of Sydney.



The next dynamic to examine is the trajectories of labour, crane and ship rates following 2013 semester 2. In Melbourne (Figure 10), all three rates increased modestly until December 2013 and all have been trending downwards since that time. In the case of crane and ship rates, December 2014 (the most current quarter) rates are lower than they were pre-2013 semester 2 (Table 2). In Sydney (Figure 11), ship rate declined markedly in 2013 semester 2, and all three rates have exhibited some volatility since then. Table 2 shows that Sydney had the most dramatic decline in multi-factor productivity since pre-2013 semester 2; ship rate has declined by more than 26%. While this multi-factor productivity indicator is a function of both labour and capital (crane rate) productivities, the relationship is not linear. Nonetheless, it is likely that declines in each of these single factors have contributed to the ship rate result. In Brisbane (Figure 12), all three rates initially declined quite dramatically up to June 2014, signalling reduced productivity.

Figure 12: Time series of wharfside productivity indicators for Port of Brisbane.



While these have trended upwards again since that quarter, December 2014 labour, ship and crane rates are lower, by more than 7.5%, than June 2013 (Table 2).

Table 2: Wharfside productivity results pre- and post-2013 semester 2 for three ports.

Port:	Rates [TEU/hr]:	Pre-2013 semester 2: Jun 2013	Most current quarter: Dec 2014	% difference:
Melbourne	Labour	66.9	75.3	12.56%
	Ship	93.6	85.9	-8.23%
	Crane	45.6	43.9	-3.73%
Sydney	Labour	68.1	63	-7.49%
	Ship	95.2	70	-26.47%
	Crane	46.1	43.7	-5.21%
Brisbane	Labour	61.1	56.2	-8.02%
	Ship	73.3	64.8	-11.60%
	Crane	43.5	40.2	-7.59%

3.3 Landside Indicators

Figures 13-15 present the time series for two landside indicators: average container turnaround time; and average truck turnaround time, in minutes, for the Ports of Melbourne, Sydney and Brisbane. Superimposed on all of the following figures is a black line denoting the 2013 semester 2 change point identified in 3.1, after which very large vessel visitation has become more frequent.

Improved efficiency is interpreted in these landside indicators as declines in turnaround time for both. Figure 13 indicates that for Melbourne, a sharp decline in turnaround time is observed around the period when very large vessel visitation increased, in mid-2013. Since then, however, turnaround times in Melbourne show a steady upward trend; and the most current figures (December 2014) indicate a 22.3% and 28.9% increase in container and truck turnaround times, respectively, since the historical minimums for this time series, achieved in March 2011 (Table 3).

Figure 13: Time series of landside efficiency indicators for Port of Melbourne

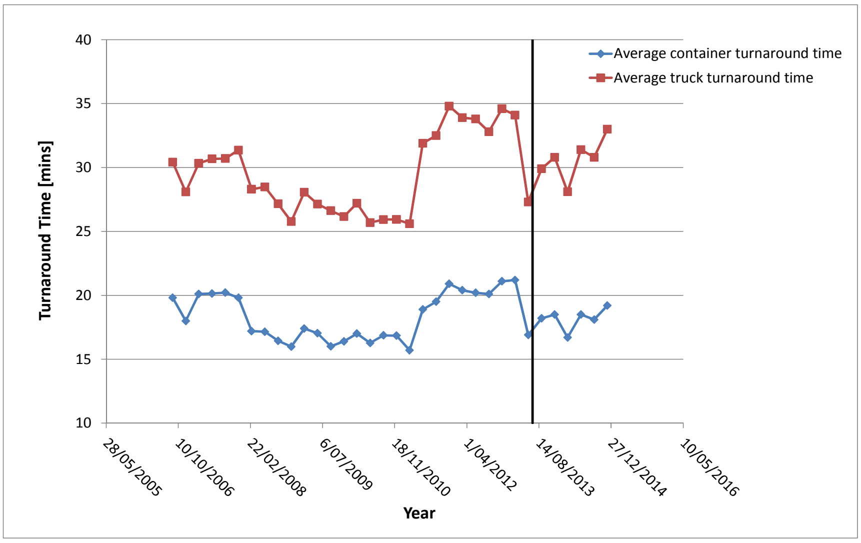


Figure 14: Time series of landside efficiency indicators for Port of Sydney

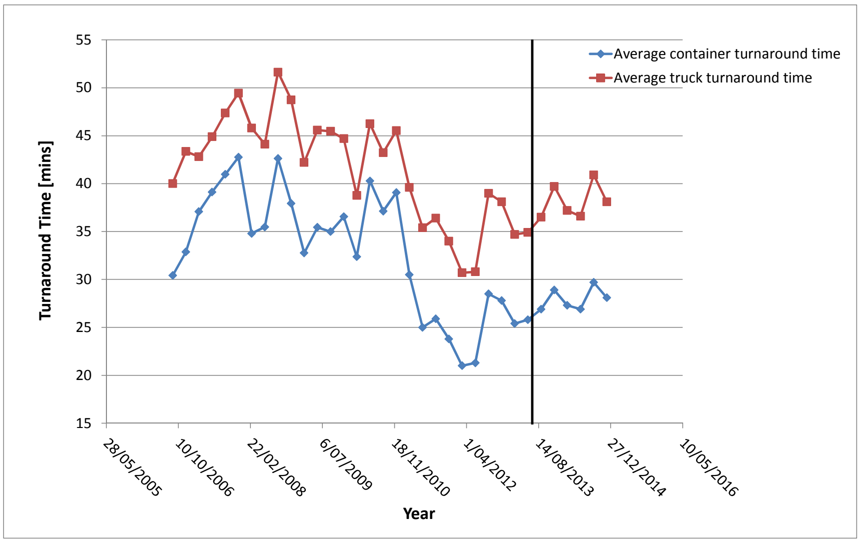
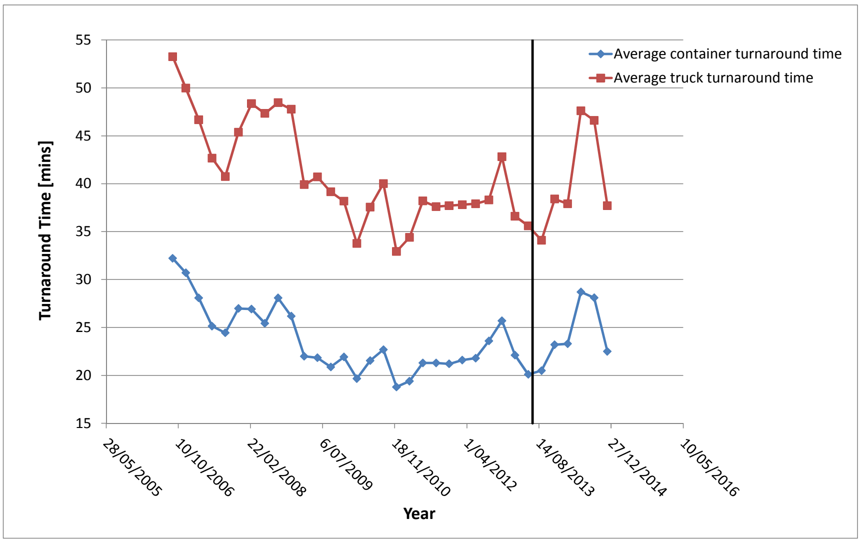


Figure 15: Time series of landside efficiency indicators for Port of Brisbane



This is echoed in Brisbane, which shows sharp increases in turnaround times since 2013 semester two. These peaked in June 2014, and have exhibited declining times since then; though the most current turnaround times (December 2014) are 3.7 and 4.8 minutes (container and truck respectively) longer than the historical minimums in these time series, which were achieved in December 2010. While these time increases in absolute terms seem modest, they are 19.7% and 14.5%, respectively, higher than the historical minimum (Table 3). In Sydney (Figure 14), both indicators have been on an upward trajectory (suggesting declining efficiency), since early 2013. Relative to the historical minimums (occurring in March 2012), December 2014 times are 33.8%, and 24.1% (container and truck respectively) higher. Of the three ports, Sydney exhibits the greatest absolute and percentage loss in landside efficiency, as measured by these indicators.

Table 3: Recent landside efficiency losses: container and truck turnaround times at Ports Melbourne, Sydney and Brisbane.

Landside Indicator:		historical minimum:	as at Dec 2014:	increase since historical minimum [mins]:	% increase since historical minimum:
Port:		**Melbourne**			
Container Turnaround Time [mins]	Time:	15.70	19.20	3.50	22.3%
	Date:	Mar-11			
Truck Turnaround Time [mins]	Time:	25.60	33.00	7.40	28.9%
	Date:	Mar-11			
Port:		**Sydney**			
Container Turnaround Time [mins]	Time:	21.00	28.10	7.10	33.8%
	Date:	Mar-12			
Truck Turnaround Time [mins]	Time:	30.70	38.10	7.40	24.1%
	Date:	Mar-12			
Port:		**Brisbane**			
Container Turnaround Time [mins]	Time:	18.79	22.50	3.71	19.7%
	Date:	Dec-10			
Truck Turnaround Time [mins]	Time:	32.93	37.70	4.77	14.5%
	Date:	Dec-10			

3.3.1 Slot utilisation for trucks transporting containers from/to ports

To provide more insight around these findings, Figures 16-19 present the time series of slot utilisation for trucks transporting containers from/to ports. Figure 16 shows the total number of slots available at the three ports. Over the period July 2007-December 2014, the number of slots has steadily increased at all three ports. Brisbane slots increased by 58.5%, from 98,283 to 155,729; Sydney slots increased by 53.1%, from 168,936 to 258,570; and Melbourne slots increased by 75.8%, from 192,107 to 337,694. Figure 16 shows a specific increase in slots available at all three ports in 2013 semester 2.

Figures 17-19 show the proportion of these slots that were utilised, and show high utilisation rates across all three ports in 2012. In dynamic response to demand, 2013 saw increased capacity provided (in the form of additional slots being made available), and this resulted in the declines in proportions utilised seen in Figures 17-19 from 2013 onwards. As at December 2014, Melbourne exhibits the highest proportion of utilisation, and is again approaching full utilisation above 95% across all days of the week. Melbourne is also Australia's largest port in terms of container throughput. As at December 2014, Sydney was still exhibiting some spare availability, with utilisation rates ranging from 89-91%; for Brisbane, utilisation was 85-94%.

Figure 16: Total number of truck slots available, July 2007-December 2014: Ports of Brisbane, Melbourne and Sydney

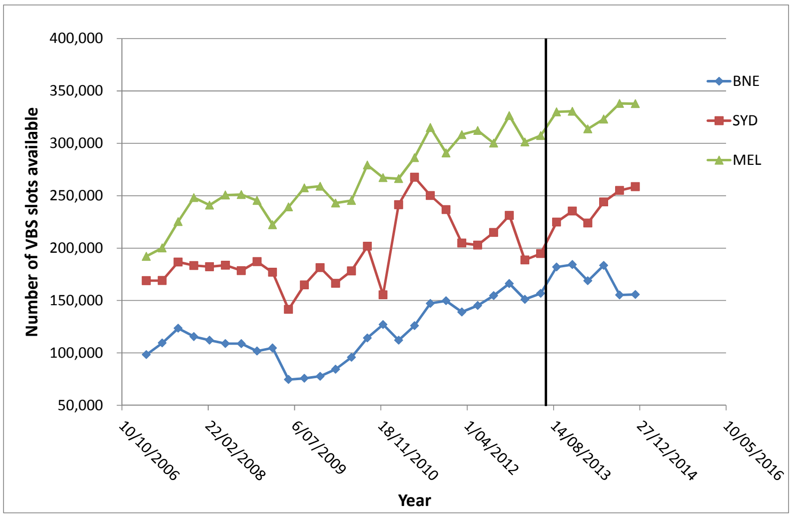


Figure 17: Proportions of available truck slots utilised - time series for Port of Melbourne

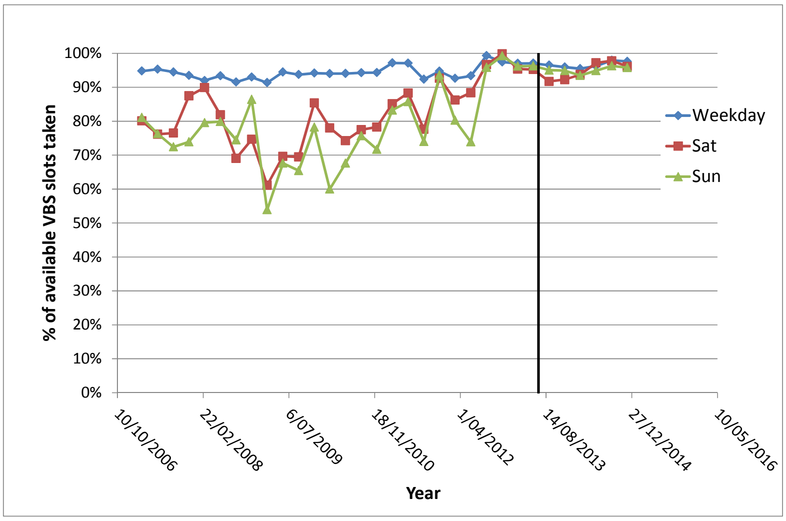


Figure 18: Proportions of available truck slots utilised - time series for Port of Sydney

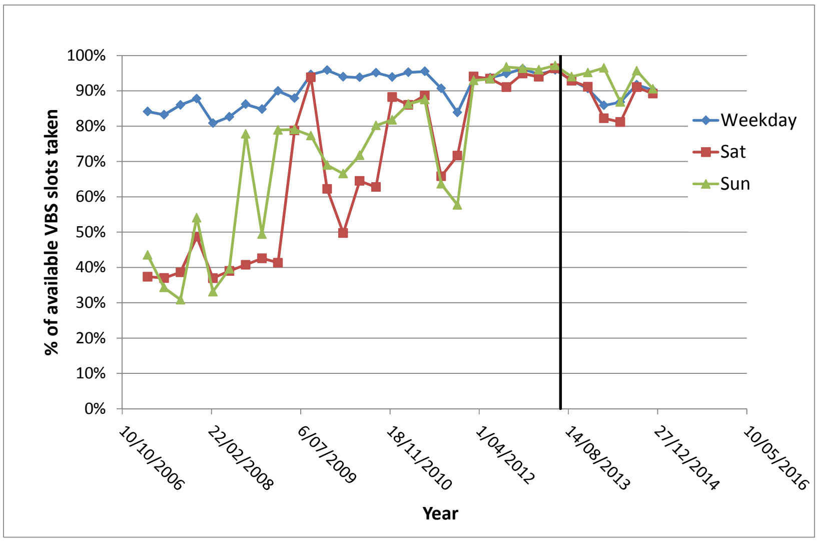
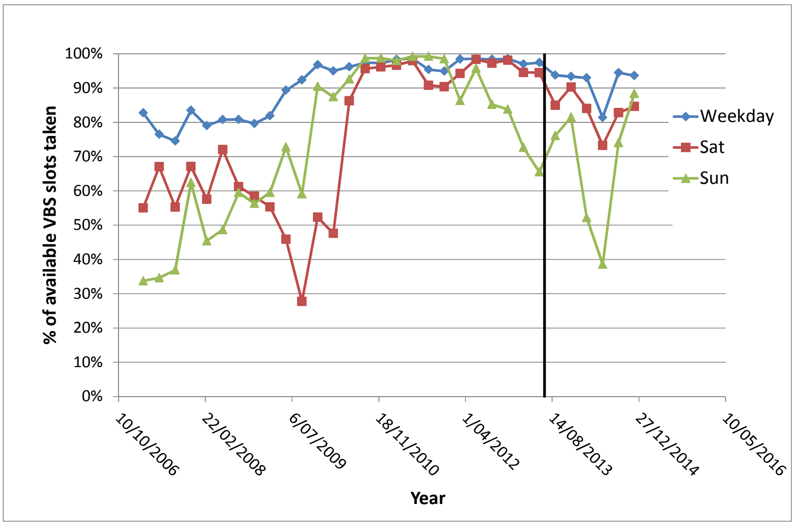


Figure 19: Proportions of available truck slots utilised - time series for Port of Brisbane



4. Discussion

4.1 Wharfside Indicators

The declines in wharfside productivity indicators presented in Section 3.2 require careful interpretation. While there does appear to be a timing coincidence with increased very large vessel visitation, this is insufficient to imply a causal relationship, and many factors may be contributing to these results. Historically, volatility in labour rates especially has been associated with industrial relations issues. However, the evidence for this during the period in question (June 2013 – December 2014) is not clear. Nonetheless, terminal operations are complex and we do not have full visibility over key operational aspects and contextual factors required for a thorough interpretation.

4.2 Landside Indicators

Section 3.3 showed that container and truck turnaround times have been on an increasing trajectory since 2013 semester 2. There is a range of factors that may be contributing to the loss of landside efficiency in the three largest ports. However, the timing coincidence of increased very large vessel visitation (clearly apparent in Melbourne, Brisbane and a lesser extent Sydney) constitutes evidence that very large vessel visitation may have contributed to the loss in landside efficiency. The evidence presented in Section 3.3.1 suggests that the landside components have responded over this period (by making additional truck slots available); and since 2013, this extra capacity has been appropriately scaled, and is yet to be fully utilised, at least in Brisbane and Sydney. The relationship between container and truck turnaround times and slot utilisation for trucks transporting containers from/to ports is revealing. The slot scheduling systems were designed to increase efficiency in landside container handling. However, the evidence shown in Section 3.3.1 suggests a loss in landside efficiency, in the form of increased container and truck turnaround times at all three ports. However, an important caveat pertains to the slot utilisation data: these represent the slots advertised, not necessarily the maximum potential slots available in each time window. The number of slots advertised per hour during weekday peak-periods is much higher than weekday off-peak and weekends. This suggests there is significant spare capacity to advertise more slots during off-peak periods and weekends. If high utilisation of weekday peak slots is contributing to increased turnaround times, shifting some of this traffic to off-peak and weekend slots may help to reduce turnaround times. The economic incentives around inducing this behaviour constitute an important future research topic, and may consider competition issues and the contribution of maximum utilisation of labour and capital to future improvements in productivity and efficiency.

4.3 Implications

The most likely manifestation of near-term growth in container exchange at Australia's ports is a higher frequency of visitation by very large vessels. The degree to which this may impact port performance requires further analysis. More detailed exploration of operations is required to ascertain the current and future relative influence of very large vessel size, and a range of other contextual factors contributing to port performance.

A first step towards this involves higher temporal resolution data: tracking labour, crane and ship rates for individual vessels, rather than aggregating means and totals to a quarterly time step (the data presented here). A second step involves expanding and refining the set of indicators. We note that this is contingent upon voluntary data provision by key port stakeholders.

Such an analysis will also be helpful in examining the real and perceived limits to port productivity and efficiency, and the relative contributions of labour and capital. For example, improved wharfside productivity will not necessary improve overall port performance if landside efficiency is or becomes the limiting factor. Our landside analysis suggests there is scope for operational improvements; these, and capital investments should be explored to identify the most cost-effective means of improving port productivity and accommodating future growth.

Clearly a terminal view of productivity and efficiency is required (Wang and Cullinane, 2006). Given the number of stakeholders involved across the supply chain, close integration (and potential exploitation of some of the benefits of smart technology) is essential to optimising terminal productivity and efficiency. At the micro-economic level: each operator may be optimising their own operations as a single step in the chain: but this does not necessarily equate to overall optimisation at the terminal level. This poses challenging questions, for both port stakeholders and government: firstly on how to address such an inter-connected problem; and secondly the respective roles of government and the private sector in this supply chain integration. It is clear that more detailed data and analysis, at a terminal level, are essential in addressing these challenges.

5. Conclusion

This paper presented an initial analysis of increased very large vessel (>55,000 GT) visitation to Australia's container ports, and examined the coincident changes in selected, partial indicators of port productivity and efficiency. Over the 2013-14 period, 12.7% of first-visit vessels were in the very large size class, around 20 vessels. While currently a modest proportion of the total fleet, these vessels are contributing to significant growth in TEUs exchanged due to their larger TEU carrying capacity. A sharp upturn in the number of very large vessels visiting Australia's ports occurred in 2013 semester 2.

To examine coincident changes in wharfside productivity, we compared labour, crane and ship rates for the most current quarter (December 2014) with the pre-2013 semester 2 results. With one exception (labour rate in Melbourne, which increased by 12.6%), these rates have declined at all three ports over this period, with Sydney's ship rate (-26.5%) the strongest decline. Landside, container and truck turnaround times have increased substantially at all three ports following 2013 semester 2, and the most current quarter (December 2014) results are up by 14.5-33.8% from historical minimums achieved over 2010-2012. A closer examination of landside efficiency in the form of slot utilisation for trucks transporting containers from and to ports shows that while the number of slots has been increased to handle increased throughput, this mechanism alone has been insufficient to improve concurrent declines in landside efficiency, particularly at Melbourne and Sydney. Further, some spare capacity in weekday off-peak and weekend periods is apparent, suggesting operational improvements are feasible. While the timing suggests that very large vessel visitation may be associated with these declines, there are a broad range of factors potentially contributing to these performance results, and these warrant more detailed analysis in collaboration with port stakeholders. Future growth in container throughput at Australia's ports is likely to manifest in increased frequency of visitation from very large vessels. To maintain or improve Australia's port performance in the face of this increased visitation, a terminal view of productivity and efficiency is critical in optimising operations, achieving supply chain integration, and guiding investment decision-making. This poses a significant challenge for port stakeholders and Government.

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