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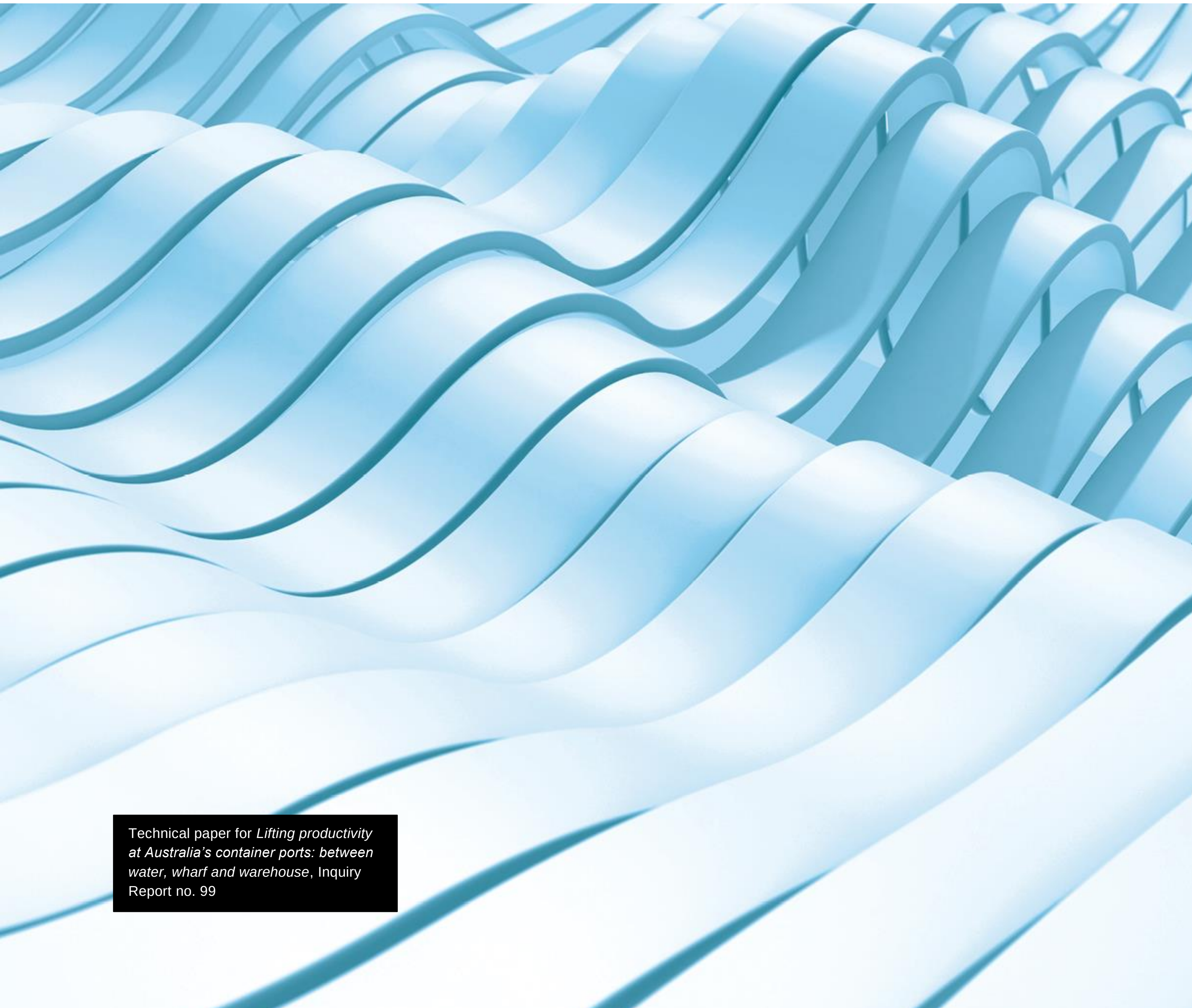
Container port productivity

Technical paper



Technical paper for *Lifting productivity at Australia's container ports: between water, wharf and warehouse*, Inquiry Report no. 99

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Publication enquiries:
Media, Publications and Web | phone 03 9653 2244 | email publications@pc.gov.au

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Container port productivity

This technical paper assesses the performance of Australia's major container ports, with a focus on benchmarking their productivity against each other and against similar international ports. The analysis also takes a long-term productivity focus where the data permits.

This paper supports and extends the discussion presented in chapter 3 of the inquiry report *Lifting productivity at Australia's container ports: between water, wharf and warehouse* (the inquiry report). It is intended to be a standalone piece and therefore contains some repetition of that chapter's content.

The paper:

- describes what the Commission has been asked to do (section 1)
- highlights some of the motivations for the analysis (section 2)
- describes why port performance matters (section 3)
- describes how to measure port performance, including what constitutes a container port and the inputs and outputs used to assess productivity (section 4)
- develops a conceptual framework for assessing port productivity and examines how the existing framework could be extended (section 5)
- assesses the performance of Australian container ports, presenting long-term trends where possible (section 6)
- assesses how Australia's major container ports compare to ports overseas, unpacking the World Bank's study results and benchmarking the performance of Australia's container ports internationally in the process (section 7)
- summarises the key takeaway messages from the analysis (section 8).

Appendices to the paper provide further information on data sources, supplementary figures and tables, literature reviewed and a detailed summary of the World Bank's Container Port Performance Index (CPPI).

1. What the Commission has been asked to do

The terms of reference direct the Commission to:

> Examine the long-term trends, structural changes, and impediments that impact the efficiency and dependability of the maritime logistics system, including developing a framework of performance measures to determine port performance and benchmarking Australian ports internationally.

Port performance encompasses the efficiency and dependability of ports. This technical paper focuses on analysing one dimension of efficiency — technical efficiency (or productivity) which is how effectively ports use their inputs to produce their outputs. The technical paper also references dependability where data permits.[1]

[1] Dependability covers whether goods are delivered undamaged/unspoilt and certainty around container delivery/departure. Certainty enables importers/exporters to plan their businesses with greater confidence.

As per the primary scope of this inquiry (chapter 1, inquiry report), this paper focuses on the performance of major container ports. Reflecting where the majority of containers are handled and data availability, the paper focuses on the five main Australian container ports: Brisbane, Sydney, Melbourne, Adelaide and Fremantle.[2]

These container ports also handle other types of cargo. For example, the port of Melbourne also handles: motor vehicles; bulk liquids from petrochemicals to crude oil and molasses; dry cargo including cement, sugar, grain, and gypsum; breakbulk commodities such as timber, paper, iron and steel; and a variety of non-containerised pack types including farm equipment and machinery. These non-containerised activities are not included in the subsequent analysis.

Measurement of long-term trends in container ports requires extensive time-series data. It also requires the ability to identify and exclude the effects of short-term influences from the data and analysis. The COVID-19 pandemic led to many disruptions in the maritime logistics system, including shipping delays, quarantine of supply chain workers, surges in demand and price spikes. Long-term trends are presented where data permits, allowing for the impact of the pandemic between 2020 and 2021 to be noted.

2. Motivating concerns about port performance

A motivating factor for this inquiry was the poor performance of Australian container ports in a recent international study undertaken by the World Bank in conjunction with IHS Markit (2021).[3] This study developed a Container Port Performance Index (CPPI) to enable comparisons of quayside performance, and assessed performance across 351 container ports in 2019-20. The CPPI was the first attempt at a comprehensive cross-sectional international comparison of container port performance using a consistent dataset. Earlier international studies focused on benchmarking far fewer ports, and each used data compiled from numerous and different sources (appendix C). The CPPI is intended to be released annually. The inaugural study was released in 2021 and the second edition was published in May 2022.

For the CPPI, port performance was measured with reference to port hours (that is, the time from when a ship reaches the port limit to the time it departs from the berth; this covers anchorage, steam in and cargo handling operations). The rationale is that more efficient ports handle a given ship-call-size combination more quickly than less efficient ports (where call size represents the number of containers unloaded and loaded on a ship's visit).

Nearly all Australian container ports ranked in the bottom 20 per cent of the ports assessed in the inaugural report (table 1). The exception was Brisbane, which ranked in the bottom 30 per cent. These results suggest that Australian ports took longer than most international ports to turn ships around. The port of Yokohama in Japan was found to be the most efficient container port globally, followed by the port of King Abdullah in Saudi Arabia.

[2] A recent World Bank study also included Bell Bay Tasmania (which was serviced by the international shipping line MSC), and their data source also included Townsville in Queensland. In keeping with official Australian data sources, this paper focuses on the five main container ports. These ports are listed in the order in which international shipping lines generally service them. Sydney refers here to the container port at Port Botany (as Sydney has more than one port).
[3] IHS Markit supplied the Port Performance Program data used in the study. The Program collects data from ten of the world's largest shipping carriers (accounting for 76 per cent of global capacity).

Table 1 – Australian container ports rank poorly in the World Bank's Container Port Performance Index (CPPI)[a,b]

Sample of 351 container ports, 2019-20

	Statistical approach		Administrative approach	
Port	**Rank**	**Total score**	**Rank**	**Total score**
Brisbane (QLD)	246	+0.569	234	-8
Sydney (NSW)	337	+3.907	327	-63
Melbourne (VIC)	302	+1.676	313	-40
Adelaide (SA)	339	+4.546	333	-78
Fremantle (WA)	326	+2.716	319	-49
Highest ranked	**Rank**	**Total score**	**Rank**	**Total score**
Yokohama (Japan)	1	-5.995	1	130
King Abdullah (Saudi Arabia)	2	-5.684	2	114

a. The statistical approach used factor analysis to identify the relevant factor weights for each input. Total scores can be negative (more efficient) and positive (less efficient). **b.** The administrative approach calculated an index that arbitrarily weights each input. The higher the index, the more efficient a port is found to be. The index can be positive (more efficient) or negative (less efficient). Both approaches are discussed in more detail in the accompanying technical paper.

Source: Adapted from the World Bank (2021).

The performance of Australian ports was still poor in the second edition of the CPPI which drew on data for 2021 (World Bank 2022). The rankings in this second report reflected the effects of the COVID-19 pandemic on performance. For example, the Port of Los Angeles and Port of Long Beach were ranked at the bottom, which is unsurprising given the backlog of ships anchored and waiting to dock at these ports during the COVID-19 pandemic.

The COVID-19 pandemic may also have affected the results for the inaugural CPPI study for 2019-20. The World Bank analysed shipping calls between July 2019 and June 2020, a period which covered the onset of the pandemic and ports that faced disproportionately more disruptions (such as ships arriving off schedule or COVID-19 outbreaks among dock workers) likely ranked lower due to longer port hours.

Given the widespread media coverage of supply chain issues during COVID-19, the World Bank's ranking of container port performance attracted considerable attention, and criticisms of the CPPI have been raised in submissions to this inquiry (box 1).

Overall, most submissions that commented on the World Bank report questioned the validity of the results and cautioned against drawing conclusions about Australian port productivity based on the CPPI. In particular, DP World (sub. 49, p. 7) highlighted that the study 'cannot precisely identify the cause of delays — including the extent to which these are caused by poor productivity or other (exogenous) factors', which limits the usefulness of the CPPI. DP World concluded that:

> CPPI data is almost entirely limited to vessel turnaround time, in the limited sense of operational times. This is a narrow view of port productivity and one that DP World does not accept reflects "port performance" nor does it provide a meaningful way to compare the relative performance. (sub. DR140, p. 2)

Box 1 – Some inquiry participants criticised the World Bank study

Many submissions to this inquiry raised concerns that the World Bank study had not compared like-for-like ports (ALC, sub. 57, p. 9; FPH, sub. 55, pp. 10–11; MUA, sub. 59, p. 70; NSW Ports, sub. 66, p. 17; Peter van Duijn, sub. 39, p. 7; Ports Australia, sub. 45, p. 4). Particular concerns included that it did not differentiate ports by:

- the amount and type of trade
- the ship sizes serviced
- the function of the ports (transhipment versus destination/origin ports).

The Maritime Union of Australia (sub. 59, p. 71) also noted that few of the top ranked ports had similar labour and human rights standards to Australia. In noting these factors as concerns, inquiry participants suggested that these factors likely contributed to the poor rankings of Australian ports.

Inquiry participants also noted other criticisms relating to the focus of the CPPI study on:

- port hours as the key measure of performance, which misses other important indicators of port performance, such as container dwell times and landside performance (DP World, sub. 49, pp. 6–7; Peter van Duijn, sub. 39, pp. 7–8)
- the interests of one key stakeholder (the shipping lines) (MUA, sub. 59, p. 83)
- port-wide performance rather than terminal-level performance. Some participants advocated for performance to be measured at the terminal level because the productivity of individual terminals within a port differs (NSW Ports, sub. 66, p. 17; Ports Australia, sub. 45, p. 4).

However, in its submission, Shipping Australia Limited (sub. 11, p. 102) advocated for the CPPI to be included as part of the port performance monitoring framework. They acknowledged that, while the CPPI would always attract criticisms, ‘if two separate methodologies, devised and implemented by world-leading transport economists, both rank the performance of Australian container ports badly, then … it is not the methodologies that are at fault’.

Two of the main criticisms focused on the failure of the study to:

1. ensure like-for-like comparisons across ports, given perceived differences across them, particularly in terms of throughput, differences in the size of ships that visit each port, and whether the ports were transhipment or origin and destinations ports[4]
2. take into account the efficiency of landside operations of each port.

There is some validity to each of these criticisms. While it did not receive much prominence, the published indexes did take ship and call size into account to facilitate greater comparability across ports. The analysis did not, however, differentiate between transhipment and origin/destination ports. Moreover, collecting landside data is difficult given the differences in landside operations and numerous firms involved. Therefore, the absence of a consistent, comparable global dataset precludes the inclusion of landside operations

[4] Transhipment ports pass the bulk of the cargo unloaded from one ship to another ship. These ports are typically the ‘hub ports’ in the series of ‘hub and spoke’ networks that service international maritime trade. These ports are strategically placed on, or close to, major international shipping routes and channels (such as the Panama Canal, the Strait of Malacca, the Suez Canal and the Straits of Gibraltar) and typically handle much larger ships than other ports. Transhipment ports include, for example, Singapore, Port Said and Cristobal.

across the 351 ports analysed.[5] The World Bank recognised and acknowledged many limitations in their report, and they intend to enhance the methodology, scope and data in subsequent reports.

Despite these criticisms, it is worth noting that the number one ranked port, Yokohama, is similar in size (that is, it handles a similar number of containers annually) to Melbourne and Sydney and could therefore be considered ‘broadly comparable’.

The findings of the World Bank study are similar to many previous empirical studies on the performance of Australian container ports relative to international ports (appendix C). For example, in one somewhat dated OECD study, Merk and Dang (2012, p. 35) found that Australian container ports were relatively inefficient in an international context. (In contrast, the study found that Australian bulk ports were among the most efficient in the world (p. 19, 22), particularly Port Walcott (iron ore) and Gladstone, Newcastle and Hay Point (coal). There has been limited national or international performance benchmarking of bulk ports; presumably a reflection of their diversity.)

Unfortunately, the World Bank study did not identify *why* Australian container ports ranked so poorly nor *what* they could do improve their performance and world ranking, especially given that many of the drivers of performance may be outside the control of individual port operators (such as the demand for imports in Australia and world demand for Australian exports, the size of ships operated by international shipping lines and service frequency). These issues are explored in section 7 of this paper.

3. Why port performance matters

Ports are vital to the functioning of the Australian economy

Ports play a critical role in the maritime logistics system and hence, in the global economy. As the World Bank (2021) explained:

> [m]aritime transport carries more than 80 percent of global merchandise trade by volume, and any impediment or friction at the port will have tangible repercussions for their respective hinterlands and populations. In the short term, this is likely to take the form of shortages of essential goods and higher prices, as we saw early in the pandemic. But over the medium to longer term, an inefficient port will result in slower economic growth, lower employment, and higher costs for importers and exporters. (p. 8)

Most goods that enter Australia pass through container ports (aside from crude oil, motor vehicles and petroleum), as do most manufactured and processed exports.

While details on the number of containers handled exist, it is hard to be definitive about the share of Australian imports and exports that pass through Australian container ports, or even ports more generally (that is, including containerised and non-containerised trade) using data from public sources.

In its submission to this inquiry, Shipping Australia Limited (sub. 11, p. 6) attempted to identify the share of trade passing through Australian ports by combining data from different official sources. The submission noted some material differences in the value of goods trade that passes through airports and seaports across sources. Shipping Australia estimated that seaports handled 99.93 per cent of all trade (imports and exports) by volume, and 83.6 per cent by value in 2018-19. These estimates were not broken down between imports and exports and between container and non-container trade. The ABS publishes the volume and

[5] Moreover, while partial measures of landside productivity exist for Australian container ports (such as truck turnaround times), comprehensive measures of landside productivity do not exist.

value of maritime trade by port, but likewise does not differentiate between containerised and non-containerised trade. The lack of distinction in the type of trade is particularly an issue for ports that handle multiple types of cargo because the value of containerised trade cannot be distinguished.[6]

The efficiency and dependability of Australian ports affect the cost of importing and exporting goods, and, consequently, play a role in determining the international competitiveness of many Australian businesses in global markets and the cost of goods purchased by Australian households. The performance of Australian ports ultimately affects the living standards of all Australians.

Growth in containerised trade is forecast for Australia (chapter 1, inquiry report). Moreover, ships are getting bigger and, with this, so are their call sizes (chapter 2, inquiry report). These trends are expected to continue. Ports will need to be efficient to be able to deal with the projected growth in the number of containers handled annually and per ship (that is, the throughput and call size).

Productivity is integral to the efficient functioning of ports

Productivity is the effectiveness with which container ports use their inputs to produce their mix of outputs (either individually or collectively) (box 2). This is sometimes referred to as 'technical efficiency'. Being technically efficient is a prerequisite for productive efficiency — when a given quantity of output is produced at the lowest possible cost — and for overall efficiency (chapter 1).[7]

A port that is *technically efficient* uses the fewest inputs possible to produce a given level of output. In other words, given the prevailing technology, it is not possible to reduce the use of any input (such as cranes or labour) at this port without reducing the level of output (such as the number of containers passing through the port).

Ports may also be technically efficient in the use of one, but not all, inputs. In this case, they could produce the same level of output using less of some, but not all, inputs. An example of this might be a port that used its cranes efficiently but had an excess of labour inputs for the level of throughput handled.

Being technically efficient, however, does not necessarily mean that the existing level of throughput is being achieved in the most cost-effective way. For example, it may be that a port is fully efficient in the use of manually operated cranes and labour, but these manual cranes may cost more in the long run than fully automated cranes (chapter 11, inquiry report). So, even if fully automated cranes are unable to move more containers or move them more quickly than manual cranes, investing in fully automated cranes would reduce a port's overall costs in the long run (by reducing labour costs). Such an investment would alter the mix of inputs used (in this case, using more capital and less labour) with resultant benefits to profitability (and, potentially, overall productivity).

[6] The Bureau of Infrastructure and Transport Research Economics is working with customs data from the Department of Home Affairs to generate statistics that differentiate between containerised and non-containerised trade in the future (BITRE, pers. comm., 2 December 2022).

[7] This gives rise to two different representations of technical efficiency. The first measure relates to the extent to which the existing level of output could be produced using *fewer* inputs (referred to as 'input-augmenting technical change'). The second measure relates to the extent of the *increase* in output that could be achieved from the existing inputs (referred to as 'output-augmenting technical change'). Curvature of the underlying production function means that these two measures will often differ. This chapter focuses on the potential for input-augmenting technical change because, as far as ports are concerned, the demand for imported containers is outside their control.

Box 2 – Different measures of productivity

Different types of productivity measures exist, with many relating to the choice of inputs.

Partial productivity measures relate to the use of a single input (such as capital or labour). Examples relevant to ports include lifts per crane per hour (capital), containers moved per hour worked (labour) and containers moved per berth metre (capital). Partial productivity measures may also differ in the measure of output used (such as container movements or the number of ship calls).

Productivity measures can also relate to the use of groups of inputs (such as the use of capital and labour, often called value adding factors, or all inputs, referred to as total factor productivity). Such measures of productivity are uncommon for ports. Value added and total factor productivity measures are frequently used in studies that cover broader ranges of economic activity and are used by the Australian Bureau of Statistics in the Australian System of National Accounts.

Technical efficiency is one of several measures of economic efficiency (box 3). Technical efficiency is a prerequisite for productive efficiency — which occurs when a given quantity of output is produced at the lowest possible cost.

Measuring technical efficiency (in the form of productivity levels) is useful in benchmarking the same activity in one port against another. This benchmarking can provide useful insights into how port productivity and practices can be improved and to identify which ports to learn from. Care is still needed in analyses of this type as any undue focus on an individual performance measure may miss wider issues (including the trade-offs between different activities, as one port may not be good at everything). For example, a port may be the fastest at unloading containers but the slowest at getting those containers out the gate and to customers, and as a result has a congested container yard.

Growth in productivity is often more informative than point-in-time measures when assessing an individual port because it details how productivity has changed over time (such as whether improvements are occurring and whether this is coming from using inputs more efficiently or from output growth with a comparatively small increase in inputs).

Box 3 – Requirements for economic efficiency

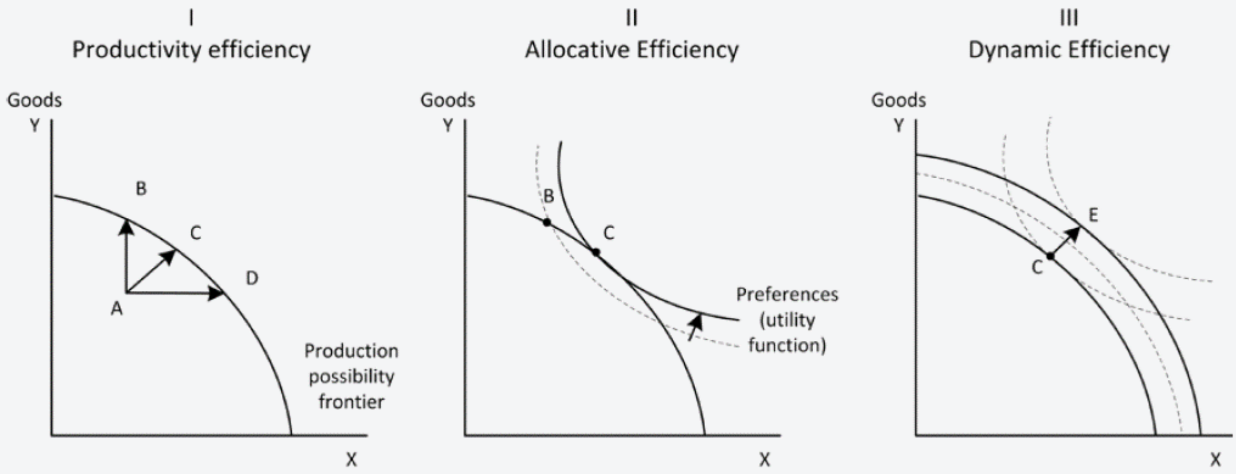
The concept of efficiency has several dimensions. Overall economic efficiency requires satisfaction of productive, allocative and dynamic efficiency.

- Productive efficiency — goods or services are produced at the least possible cost for a given quantity or quality. This concept goes beyond technical efficiency, which is the lowest volume of inputs per unit output for each possible combination of inputs, as it takes into account the prices of the inputs. An inefficient firm reduces productive efficiency, for example, by not maximising its output given its mix of inputs, or by choosing a more expensive mix of inputs than required. (An increase in productive efficiency can be represented by moving to a production bundle closer to the production possibility frontier. However, only one point on that frontier will be cost minimising and, hence, meet productive efficiency.)

Box 3 – Requirements for economic efficiency

– Technical efficiency is the conversion of physical inputs such as labour services and raw materials or semi-finished goods into outputs. It is determined by the difference between the observed ratio of combined quantities of an entity's output to input and the ratio achieved by best practice. It can be expressed as the potential to increase quantities of outputs from given quantities of inputs, or the potential to reduce the quantities of inputs used in producing given quantities of outputs.

- Allocative efficiency — the type and mix of different goods and services produced are of the highest value for consumers compared with any alternative use of the given resources. A lack of effective competition can mean that firms have an incentive to maximise profits by reducing supply and raising prices. This reduces allocative efficiency as it results in an underproduction of particular goods or services. (An increase in allocative efficiency can be represented by a movement along the production possibility frontier that places the community on a higher utility curve.)
- Dynamic efficiency — productive and allocative efficiency are achieved over time. This can mean finding better products and better ways of producing goods and services. (An increase in dynamic efficiency can be represented by a shift outwards of the production possibility frontier.)



Sources: PC (2013, p. 3, 2019, p. 69).

4. Measuring port performance

The exercise of measuring container port productivity raises two key questions.

1. What constitutes a 'container port'?
2. What physical outputs and inputs should be used to assess port productivity?

What constitutes a 'container port'?

Container ports undertake of a range of separate, but inter-related, activities. These include:

- a port authority — the agency or company that has overall responsibility for the port

- container terminal operators (also referred to as stevedores in Australia) — the companies that employ the labour used to load and unload ships and that frequently invest in the cranes, land and other infrastructure needed to move containers from ships to other forms of transport such as road, rail or ship (and vice versa)
- pilots — who are responsible for navigating ships safely into harbour
- tug operators — who assist pilots to manoeuvre ships safely through the port to and from assigned berths
- container park operators — which manage the flow and stock of empty containers
- road (trucks) and rail (trains) transport within the perimeter fence that surrounds the port — which carry containers to and from the port
- ancillary services such as customs and quarantine — which affect the speed at which goods flow through ports.

The maritime logistics system also includes other activities such as transport outside the port fence and freight forwarders (chapter 2, inquiry report).

The disparate nature of these activities means that productivity analyses do not, in practice, assess an entire container port. Instead, ports are usually assessed on activities connected with:

- *marineside operations* — the on-water activities involved in bringing ships into and out of port
- *quayside operations* — the activities that occur at the interface of the ship with the land when it is berthed, including the loading and unloading of containers
- *landside operations* — the movement and temporary storage of containers in the container yard and the loading or unloading of containers on to land-based transport (typically trucks or trains) and the passage of that transport into and out of the port.[8]

The most common metrics of port performance published in Australia relate to their quayside and landside operations (discussed below).

Notwithstanding that their results are presented in terms of ports, most international port benchmarking studies, including the World Bank's CPPI, focus on quayside operations.

What outputs and inputs should be used to assess productivity?

The most common measure of container-port output is throughput — denoted as either the number of containers handled, or the number of 20-foot equivalent (TEU) containers handled.[9] A less common measure is the number of ship calls, but this measure fails to account for the number of containers that pass through the port — the main function of a container port.

The main inputs of container ports are berths, quay cranes, labour, container yard area and land-based cranes. These can be broadly grouped into capital, labour and land. Container ports also use a wide range of standard business inputs such as offices, information technology, vehicles, fuel, legal and accounting services, telecommunications, electricity and water. Some empirical studies also include the number of container terminal operators as an input.[10]

[8] Some landside operations may be involved in transhipping a container onto another ship (such as temporary storage in a container yard). Such operations are relatively small in the Australian context.
[9] The difference between these measures reflects the size of the containers handled. The movement of one forty-foot container (FEU) constitutes the movement of one container that is equivalent to two 20-foot containers (TEU). The TEU is the international standard size measurement for maritime containers.
[10] The premise being that ports with more terminal operators have increased competition and are therefore likely to be more productive.

Inputs and outputs may be expressed in terms of physical units such as the number of cranes or the number of employees, or as time-based measures such as the number of hours that a crane or employees worked or were available for use.

Productivity analysis focuses on input use and outputs produced over specified periods of time (such as a quarter or year).

Not all inputs and outputs are within the control of ports

The demand for container port inputs and outputs that drive their productivity may result from factors that are not within the control of the port or container terminal operators (table 2).

Table 2 – Some factors affecting port productivity

Factors within and outside the control of port or terminal operators

Controllable factors	Uncontrollable factors
Service and waiting time	Tidal and weather restrictions
Terminal layout and configuration	Other physical and technical constraints
Capacity development and expansion	Trade pattern, traffic type and mix
Terminal procedures	Container status, type, and dimensions
Working hours, shift/labour arrangements	Ship size and type
Type, size, and maintenance of equipment	Pattern/frequency of shipping services
Routing and stacking of containers	Arrival pattern of ships, trucks[a], and trains
Equipment allocation and deployment	Stowage plan
Berth and yard management systems	Landside and intermodal connections
ICT and Terminal Operating System modules	Customs and trade-related procedures
Reliability and level of customer service	Health and safety requirements
	Other regulatory requirements

a. The arrival of trucks is not within the control of ports because truck operators use their own discretion to book slots to pick up containers. Further, the terminal operators have no control over which operators handle the containers nor the order in which the containers are picked up or delivered at the terminal — activity undertaken by transport companies at the direction of the cargo owners.

Source: Adapted from Bichou (2013, p. 31).

Whether these factors are controllable or not at the port or container terminal level is particularly important in providing context in any performance benchmarking analysis. For example, sometimes inefficiencies may be unavoidable for ports if they are caused by factors outside of their control (such as tidal and weather restrictions). Interpreting benchmarking results therefore requires an understanding of the specific factors affecting each port's performance.

The most obvious external factor outside the control of ports is container throughput. The number of containers that pass through a port reflects the demand for imports by the local community and world demand for local exports. As such, port throughput is a 'derived' demand. Competition between container terminal operators is ostensibly about the division of port-level throughput and the cost of handling those containers (chapter 5, inquiry report).

Shipping lines also control some of the factors that drive input use by container terminal operators. The length and draught of a ship affects which berths it can dock at, the type and number of cranes needed to service it, and the height and distance that the cranes need to travel to access containers. External factors such as bridge heights, channel depth and tidal ranges also affect vessel choice. These factors may also affect port and terminal productivity, albeit indirectly.

While these 'external' factors may affect the nature of the physical inputs and outputs of a port and the use of physical inputs, terminal operators often have discretion in how they respond to these factors. Terminal operators control the number and type of cranes allocated and workforce deployed to service vessels, even if they are unable to control the size of the vessel being serviced or its call size. Thus, how container terminal operators respond to external factors means that these operators' actions may still influence their productivity.

5. A framework for assessing port performance

The terms of reference direct the Commission to develop:

> … a framework of performance measures to determine port performance and benchmarking Australian ports internationally.

Australia was at the forefront of early efforts to measure and benchmark container port performance:

> Australia was a pioneer in efforts to [develop] efficiency metrics, as the Australian government sought to assess its waterfront reform initiatives in the late 1980s and early 1990s (Bureau of Industry Economics, 1993). The government wished to understand port performance in terms of operational efficiency and the customer requirements of timeliness and reliability. (Mary R. Brooks Transportation Consulting 2015, p. 22)

The key publication that benchmarks the performance of Australian container ports is *Waterline*, published by the Australian Government's Bureau of Infrastructure and Transport Research Economics (BITRE). *Waterline* was first published in July 1994, initially on a quarterly basis, and is now released on an irregular basis. The *Waterline* data is also one input into the annual Australian Competition and Consumer Commission's (ACCC) *Container Stevedoring Monitoring Report*.

Waterline was introduced to monitor and publish the impact of waterfront reforms on port performance. 'The Waterfront Industry Reform Authority (WIRA) monitored the progress of waterfront reform from June 1989 to September 1992, producing performance indicators at quarterly intervals' (BTCE 1994, p. 1). Self-initiated by the Bureau of Transport and Communications Economics (BTCE) in 1994, *Waterline* was designed to continue to monitor and disseminate the impacts of waterfront reform.[11] Since then, the *Waterline* report has evolved and changed in response to feedback, but monitoring has continued.

The latest *Waterline* report consists of four sections:

- measures of container terminal throughput
- measures of container terminal productivity
- vehicle booking system and empty container park operations
- a port interface cost index (used in the *Container Stevedoring Monitoring Report*).

[11] In 1992, the Australian Government directed the BTCE to produce a six monthly indicator on port interface costs; this formed part of *Waterline* (Hamilton 1999, p. 4).

Waterline also contains some commentary on the statistics and on recent developments. Earlier editions included some discussion of other related matters, such as some employment and labour market issues.

Understanding how container ports operate

An understanding of the basic anatomy of container ports is helpful to understanding the rationale for the existing framework for assessing port performance and as background to the discussion below about the frameworks strengths and weaknesses (chapter 2, inquiry report).

The role of container ports is to move containers into and out of the country. This requires linking the marineside operations of a port with its landside operations. The interface between these two areas of operation, where containers are loaded and unloaded from ships, is referred to the quayside (quayside operations). The ship's crew, employees of the port and employees of other port-related business (such as, pilots and tugs) undertake the bulk of marineside operations. Container terminal operators and their employees link the marineside and landside operations.

An efficient port, given its inputs and external constraints, minimises the collective time that it takes for containers to pass through the port (both inwards and outwards). Such ports also minimise the time that ships and land transport spend within the port. Ports that move containers more quickly, reliably and in a cost-effective manner are better performers than those that do not.

The complexity involved in moving containers gives rise to a variety of performance metrics. Some relate to different parts of the process (such as marineside, quayside and landside operations) and others relate to different metrics of performance (such as crane productivity and time-based measures).

Ports may perform well against certain metrics, while simultaneously performing less well against others.

There is no one overall metric of port performance. Instead, port performance needs to be assessed using a range of different metrics.

Container movements

Container movements are central to determining how effectively container ports operate. Focusing on imports for brevity, each container that passes through a port undergoes a series of separate, but related, broad steps:

- it enters a port onboard a ship
- it is unloaded from a ship
- it is moved to the yard
- it clears customs and quarantine and is made available for collection
- it sits in the container yard awaiting collection
- it is loaded onto land-based transport
- it exits the port on that transport (table 3).

Empty containers may also sit in container parks within ports awaiting collection. Exported containers follow similar steps, but in reverse.

Hiccups in any one of these steps add to the time taken for the container to pass through the port. At best, this adds unnecessarily to the cost of importing/exporting goods and, at worst, may lead to perishable goods spoiling, making them worthless.

Table 3 – The movement of an imported container through a port

Step	Timing required	Derived time measure
Container arrives at the port limit	Time when the ship arrives at port limit/anchorage point	
Container sits at anchorage		Time spent at anchorage
Container starts to move to berth	Time when the ship starts sailing to the berth	
Container moves to berth		Sailing time
Container arrives at berth	Time when the ship arrives at berth	
		Line fastening time
	Time when the ship lines are fully secured	
		Preparation time
	Time when labour first boards the ship	
		Unlashing time
	Time when container unloading commences	
		Container ship waiting time
Container unloaded from the ship and moves to yard	Time when the container is unloaded	
		Customs clearance time
Container clears customs and quarantine and shipping line confirms release	Time when container clears customs and quarantine and is available for collection	
		Container dwell time
Container moves to the yard to await collection	Time when the container is moved to the yard	
		Container movement time
Container moves from the yard to the truck loading bay (intermodal terminal for rail)	Time when the container is moved to the truck loading bay (intermodal terminal)	
		Truck/train loading time
Container loaded onto truck/train	Time when the container is loaded onto truck/train	
Container moves to port exit		Truck/train exit time
Container leaves port	Time when the truck/train exits the port	

Ship visits

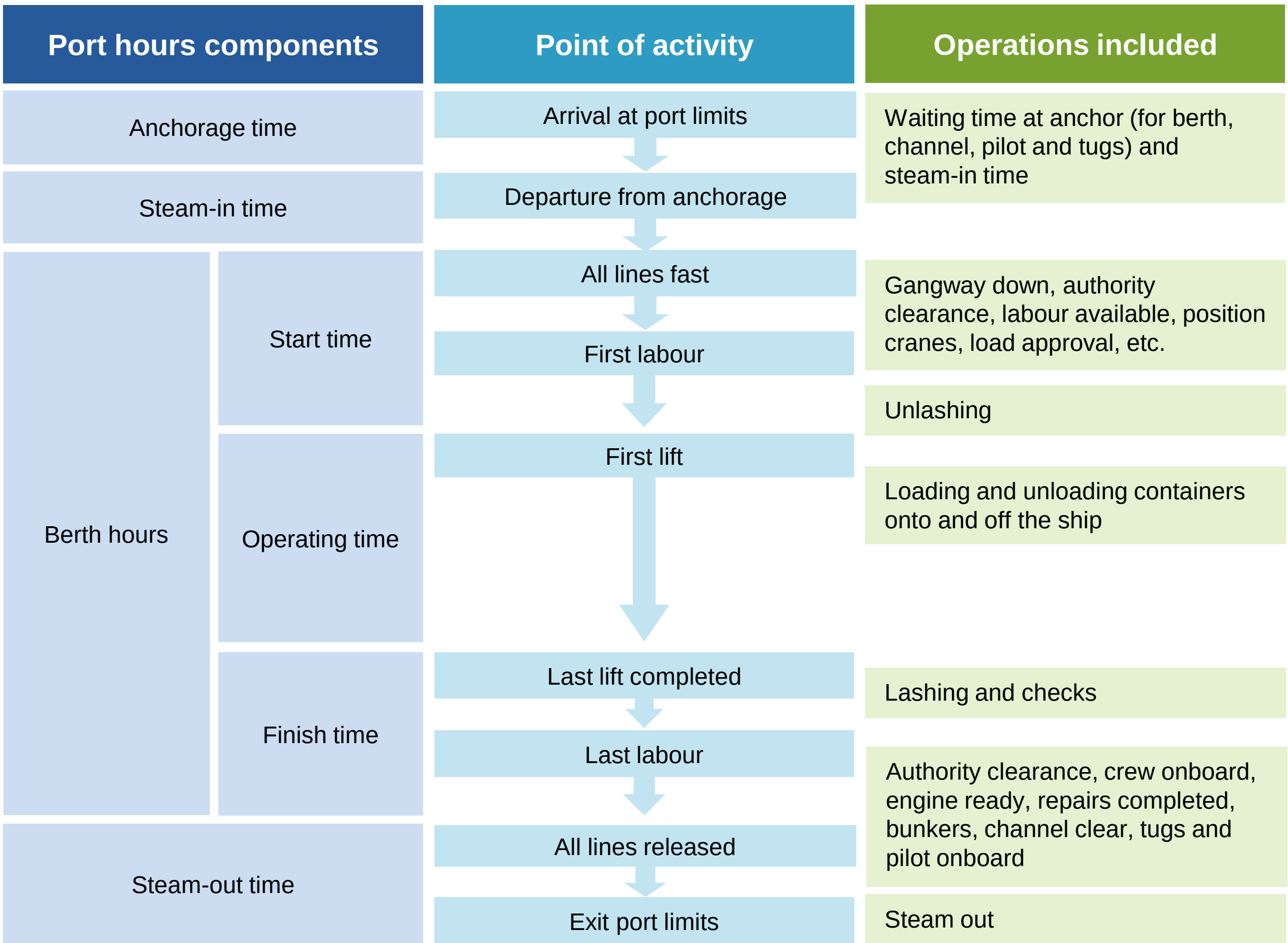
Ship visits are frequently expressed in terms of the size of the vessel that visits the port, the number of containers unloaded and loaded (referred to as the ‘call size’) and the time taken to turn the ship around.

The turnaround time is the total time that a ship spends in port (also known as ‘port hours’). This can be broken down into stages (figure 1).

Most container ships operate to schedules that set out their expected arrival and departure times. The shipping lines provide this information to ports. The ports then determine arrival ‘windows’ during which the ship is expected to arrive. These enable the port and terminal operators to plan the delivery of services to the ship and the handling of containers around these windows (such as allocating berths and providing pilots, tugs, line boats, mooring gangs, cranes, workers and fuel).

If ships miss their window or if their berths are otherwise unavailable, ships may have to anchor at the port limits and wait until a suitable berth is available (referred to as anchorage time).

Figure 1 – The anatomy of a port call



Source: Adapted from the World Bank (2021, p. 45).

Ships missing their windows also affects the reliability of the maritime logistics system. When ships miss their windows, it can disrupt operations of the port and container terminals and the delivery of goods to customers.

Anchorage time is wasted time. It may reflect port or channel congestion, the designated berth already being occupied, the terminal operator not being otherwise ready to receive the ship, or ships missing their window. And it may be a consequence of the actions of port authorities, terminal operators or the ships themselves (for example, choosing to miss their designated window for berthing to save fuel).

Ships then depart the anchorage zone and enter the port under the direction of the Harbourmaster and vessel pilot. The time taken to sail to the berth will reflect, among other things, the distance from the port limit to the berth (which varies greatly by port) and vessel type. This steam-in time is largely outside the control of port operators and container terminal operators. Ships leave the port (‘steam-out’) in a similar fashion.

The remaining time is the time that ships spend at berth. This is the time between when the lines between the ship and berth are secured (referred to as all lines fast) to when all those lines are released so that the ship can depart (referred to as all lines released).

Time spent at berth is composed of three components: start, operating and finish time. The start time is the time taken for the crew to ready the ship for boarding and for land-based workers to board the ship to unlash and unpin the containers so that they are ready to be moved. (The time when labour first boards the ship is referred to as first labour.) Likewise, finish time involves the opposite as the workers secure the containers and the crew readies the ship for sailing. (The time when labour leaves the ship is referred to as last labour.) Operating time relates to the time during which containers are ready to be unloaded and loaded (that is, from the first container movement to the last container movement). Gross operating time is the total time during which containers can be lifted, while net operating time excludes any operational and non-operational delays. The duration of operating time will be correlated with call size, the number of cranes used and crane productivity — ships with larger call sizes will generally be in port for longer.

Land transport

Land transport takes full and empty containers to and from the port. Trucks carry most containers to and from Australian container ports (chapter 7, inquiry report).

Given a port or terminal's landside inputs, a more efficient port will minimise the total time that land transport spends in the port. That is, the time between when trucks or trains enter and exit the port. The time that trucks spend waiting at the port gate also should be minimised (even though this occurs outside of the port perimeter), otherwise ports could artificially reduce measured truck turnaround times by forcing trucks to wait outside the gate. All other things equal, lower turnaround times are indicative of higher landside productivity. Further, a more efficient port will backload trucks such that trucks haul containers on both the in-bound and out-bound legs of a single trip (including empty containers that are dropped off at empty container parks within the port precinct).

The existing framework for assessing port performance

The metrics published in *Waterline* anchor to many of the concepts introduced above and form the existing framework for assessing port performance in Australia.

A range of the published throughput and productivity measures relate to port performance (table 4). These measures are published for the five main container ports (Brisbane, Sydney, Melbourne, Adelaide and Fremantle) and a 'five ports' total. Numerous metrics are expressed on both a container and TEU basis. Each productivity indicator is informative about a different aspect of port productivity. For example, containers per truck reflects the productivity of trucks that visit the port.

The focus of the quayside productivity measures in *Waterline* is on crane usage. The report does not provide information on the workforce. Three key quayside productivity measures are presented: *the crane rate*, *the elapsed labour rate* and *the ship rate*.

The three measures reported in *Waterline* are 'net' measures in that they *exclude* any operational or non-operational delays (such as standard breaks, adverse weather events or closed-port holidays). In contrast, 'gross' measures would include these delays.

As the net time will always be the same or lower than the gross time, the resulting net productivity measure will always be the same or higher than the corresponding gross productivity measure. If the net and gross measures are computed on a consistent basis, then a comparison of them will indicate the extent of delays (that is, the relationship between net and gross times indicates the duration for which cranes and/or labour were unavailable to work a ship).

One of the three measures merits further comment. Contrary to how it is often interpreted, the elapsed labour rate reveals nothing about labour productivity. The measure is defined as the number of containers handled per elapsed labour hour — the time between when labour first boards the ship to when it leaves the ship. Labour productivity is defined as output per worker or per hour worked. The elapsed labour rate does not reflect the number of workers involved nor the average number of hours they worked the ship. The crane rate, on the other hand, measures capital productivity because it reflects the number of hours that cranes worked.[12]

For this reason, the elapsed labour rate is not used to assess port performance in this inquiry.

Waterline does not publish measures of labour productivity or total factor productivity.

Gaps in the existing framework

The existing framework for assessing port performance in Australia could be improved.[13] The metrics collected in *Waterline* focus on separate areas of port performance. It is, a fragmented approach and means that there are some areas of port performance for which data is missing. Taking a more holistic view of a port and of the time it takes to move containers through helps to identify the gaps in the existing approach. These gaps relate to:

- missing metrics
- missing information on underlying distributions
- lack of more disaggregated data.

And the gaps represent areas where the existing framework could be extended.

Table 4 – Selected indicators presented in *Waterline*

Throughput measures	Definition
Number of ship visits	The number of ships handled by terminal operators
Number of containers handled	The total number of containers un/loaded on/off ships at container berths
Number of containers transported by road/rail	The total number of containers transported in all modes on the landside, either by trucks or by rail
Number of full container imports and exports	The number of full containers imported (unloaded) and exported (loaded)
Number of empty container imports and exports	The number of empty containers imported (unloaded) and exported (loaded)

Productivity measures	Definition
Marineside operations	
Ship turnaround time (median, 95th percentile)	The hours from when a ship enters a port to the time a ship leaves the port
Anchorage time (average/median)	The hours ships waited at anchorage, if a ship waited more than 2 hours
Time spent at berth	The total hours spent at berth by container ships at that port
Time available to stevedores (terminal operators)	The total hours that ships can be loaded or unloaded

[12] Labour and capital productivity are each influenced by both capital and labour initiatives. For example, improvements in crane technology may improve both the productivity of labour and capital.
[13] The extended framework could also be applied in an international context.

Productivity measures	Definition
Quayside operations	
(Net) crane rate	The number of containers handled per hour that the crane worked
(Net) elapsed labour rate	The number of containers handled per elapsed labour hour, which is defined as the time between when labour first boards the ship to when it leaves the ship
(Net) ship rate	The average number of containers moved on or off a ship in an hour. It is calculated as the (net) crane rate multiplied by the average number of cranes used
Average lifts per berth visit	The total number of containers handled divided by the number of berth visits of container ships
Average lifts per berth hour	The total containers un/loaded on/off container ships divided by the total time ships spent at berth
Landside operations	
Containers per truck	The number of containers processed through the VBS/TAS[a] systems divided by the total number of VBS/TAS trucks used
Per cent of backloaded trucks	The number of backloaded trucks as a proportion of the total VBS/TAS trucks
Average truck turnaround time (average)	The time elapsed from when the truck enters the gate of a container terminal to the time when the last container is loaded
Average container turnaround time (average)	Calculated as the 'average truck turnaround time' divided by 'average containers per truck'

a. VBS = vehicle booking system. TAS = truck appointments system.

Source: BITRE (2022).

Missing metrics

Labour metrics

Labour is a vital input in the operation of ports, playing an important role in almost all activities and therefore in the productivity of ports.[14] Workers, for example, unlash and unpin containers so that cranes can lift them from the ship and are, thus, central to the unloading of containers. Most cranes have a driver, whether seated in the cabin or operating from a remote location. A team of workers (a 'gang') usually accompanies each crane, and they operate together. Workers are also essential for other port activities. Pilots and tugboat crews, for example, guide ships into and out of port and their moorings, and harbourmasters are responsible for the safe and efficient operation of ports.

Unfortunately, no detailed data is published on the use of labour inputs — the number and type of workers, the hours that they work and their remuneration — in Australian container ports.[15] To measure labour productivity, the data would need to be collected and linked to outputs, such as the number of containers handled. This would enable measures like the average number of containers handled per person-shift or per hour worked to be constructed. This data is not currently published and as such labour productivity measures are not presented here or elsewhere. As noted above, the elapsed labour rate, which is referred to

[14] Although some terminals such as the Victorian International Container Terminal (VICT) at the port of Melbourne are often described as being 'fully automated', they still employ labour.

[15] The ABS provides some information on port workers through the Census, Labour Force and Characteristics of Employee datasets. However, none of this data is sufficiently granular to be able to be used to measure labour productivity of container terminal operations.

as measuring labour productivity, is not a *true* measure of labour productivity. The lack of labour information is a major limitation with the Australian container port data and with freight data more generally (iMove Australia 2019, pp. 4–5).

Being able to assess labour productivity could provide insights into opportunities for productivity improvements in the short term. Labour is one of the few inputs over which terminal operators have some degree of control, notwithstanding terms in enterprise agreements that may restrict or otherwise constrain recruitment, the amount and type of labour used and how it is used (chapter 9, inquiry report). Labour is also relatively more flexible than capital. Thus, understanding labour productivity is critical to improving productivity in the short term.

The Commission requested labour information in its draft report but received few responses, and those responses could not be shared publicly.

Time-based measures

Missing ship call measures

The time-based measures published in *Waterline* for ships cover many of the important parts of a ship visit, but do not cover all the stages (figure 1). For example, operating times, start and finish times, operational and non-operational delays, and elapsed labour hours are not reported.

The inability to unpack and understand what is driving the aggregate time-based measures in the *Waterline* collection precludes identification of activities in which performance appears relatively slow. For example, longer ship turnaround times may be a reflection of slow start times and inefficiencies in the activities that occur within this time (such as authority clearance, labour available and positioning cranes). Providing a more detailed breakdown of time-based measures would allow for a more precise identification of inefficiencies.

There is also an absence of ship arrival and window data. Ports may appear inefficient if many ships miss their windows and are forced to spend time at anchor. But this may be an inaccurate reflection of the port's performance. Instead, this could reflect inefficient shipping line performance (or external factors that cause ships to miss their windows) or another port (given multiport calls are a feature of Australian ports, delays at one port can cascade through the system). More detailed information on ships missing windows and arrival schedules could help to correctly attribute inefficiencies, especially in relation to anchorage times.[16]

Information published online by each port on individual ship movements indicate the raw data needed to identify ships missing windows is available. The collection and distribution of this ship-level data could provide additional information on the servicing provided by Australian ports (such as how many ships visit multiple ports and which ports they visit) and enable a closer assessment of the reliability of the shipping lines, and consequently Australian ports.[17]

Missing container dwell times

Container dwell time refers to the time a container spends in port after being discharged from a ship until it leaves the port for delivery to clients, in the case of imports; and the time containers spend in port after being

[16] Information on the productivity of pilots and tugs may also help to unpack and understand anchorage times.
[17] Further, information on the proportion of goods that arrive damaged or that are lost could provide more information on the reliability of the maritime logistics system more broadly.

delivered to the port until they are loaded onto ships, in the case of exports. Longer dwell times may reflect inefficiencies in the logistics system and result in slower delivery of goods to end customers.[18]

The published data do not cover the time that containers spend in the container yard. This data is also not linked with the time that it takes containers to enter or exit the port and for them to be unloaded and loaded quayside. Information regarding dwell times would enable a deeper understanding of where a container spends most of its time in port and may reveal areas for improvements. For example, the port of Halifax collects information on container dwell times and presents it on their website to help set and monitor performance standards and reduce yard congestion (Morley 2018).

The Commission requested more information on container dwell times in its draft report. Some information was shared, but not enough to compare all Australian ports or terminals.

Missing gross productivity metrics

Waterline presents 'net' time measures of productivity (that is, for the crane, elapsed labour and ship rates). Ideally, both net and gross measures would be made available. This would provide users with a sense of operational and non-operational delays, and the degree to which productivity could be improved by reducing those delays. For example, the net crane rate shows the maximum productivity of a crane; reducing delays could help bring the gross measure in line with the net measure.

Alternatively, providing information on the extent of operational and non-operational delays, in terms of the number of minutes lost, for example, and the relative distribution of operational versus non-operational delays, could help to identify whether these delays could be reduced.

The Maritime Union of Australia (sub. DR143, p. 36) also noted that the performance of yard cranes should be measured. There is currently no agreed metric or data on this, but the performance of yard cranes helps to shape the performance of quay cranes. Yard crane performance is to 'some extent determined by the yard configuration and yard size, while container reshuffling and stacking in the yard area can have a knock-on effect on the performance of the quay cranes' (MUA, sub. DR143, p. 36).

Missing rail turnaround times

No rail turnaround times — that is, the time it takes for containers to enter or exit the port by rail — are published in *Waterline*. To provide a complete picture of how containers move through ports this metric could be collected and reported.

Measurement issues

There are some measurement issues with the time-based metrics presented in *Waterline*.

- Truck turnaround times do not include the time taken for the truck to exit the port after a container is loaded or any time that the truck spends waiting outside the port. As noted above, ports can appear relatively efficient if trucks are forced to wait outside the gate rather than inside the port. National Road Transport Association (sub. DR106, p. 3) supported this and encouraged collection of data on the time trucks spend in holding bays.
- Presenting anchorage times for *all* ships that anchor rather than only those that anchor for more than two hours would more accurately shed light on how much time 'wastage' occurs at anchor (or how long ships are waiting for tugs and pilots).

[18] Quarantine and customs processes may also increase dwell times for some containers, therefore information on durations of customs clearances would be beneficial.

- Median port hours are not currently consistently measured across ports. Sydney and Adelaide's reported port hours do not include anchorage, steam in or steam out time and therefore are actually berth hours (BITRE, pers. comm, 2 December 2022).

Missing information on underlying distributions

The existing framework takes a high-level view of port operations and consequently, the metrics published tend to be aggregate summary statistics, such as totals, averages and medians, which summarise underlying distributions. For example, *Waterline* publishes the average and median anchorage times and the median and 95th percentile ship turnaround times. These published aggregates tell us little about the underlying distribution and may not provide an accurate representation of the underlying data. For example, average time-based metrics can be sensitive to outliers in the data (such as ships that stay at anchor for days at a time in the case of anchorage times), but median anchorage times may not capture any information about anchorage times if less than 50 per cent of ships anchor at a port.

Understanding the underlying distributions is important for assessing port performance. Information on the distributions (such as via reporting of percentiles or standard deviations) would provide insights into the reliability of the port system. A wider spread of ship turnaround times, for example, would indicate lower reliability because the port is less consistent in the time it takes to handle ships and containers. In contrast, if there is less spread in the distribution there is more certainty in ship turnaround times and in the reliability of the port system. A wider spread also provokes questions as to why port performance is so variable within a port. Only more disaggregated data can address these types of questions.

Lack of more disaggregated data

While *Waterline* reports metrics for each of the main Australian container ports, more disaggregated data would be useful for assessing port performance.

More data on ship sizes and call sizes is desirable. For example, data on the size of ships calling at each port or the call sizes for those ships is missing from *Waterline*. Without understanding these important factors, it is difficult to make performance comparisons across ports. For example, comparing the average ship turnaround time across each port can be misleading for assessing performance without taking into account ship size and, in particular, call size. Ports with larger call sizes would have longer turnaround times and thus appear relatively inefficient compared with those with smaller call sizes. Comparing turnaround times within ship and call size categories (as done by the World Bank (2021)) would allow for a fairer approach in evaluating performance.

Data on performance by terminal operator is also desirable. Performance may differ between terminal operators in a port. Metrics published reflect the average performance. These measures do little to help identify best practice among terminal operators. Providing performance metrics (confidentiality permitting) for each terminal operator may help to identify underlying trends and patterns in performance and help shipping lines make an informed decision when selecting which terminal operator to use. (International datasets, such as the one used by the World Bank (2021), do provide data at the terminal level.)

The lack of raw underlying data released is also observed as a significant gap in freight data more generally (iMove Australia 2019, p. 4).

Filling the gaps in the existing framework

Filling the gaps in the existing framework would require tracking the movement of containers, ships, trucks and trains throughout the duration of their time spent in port and at the various stages of port operations.

Some time-based metrics are collected and published in *Waterline* but others (such as container dwell times) are notably absent (figure 2). The reporting of labour productivity measures is also an important gap to fill.

The suggested extension of the existing framework would place greater emphasis on time-based metrics, greater cohesion of time-based metrics across port operations, and more disaggregation of the data. This is similar to the approach used for ship calls by the World Bank (2021) and a port-wide approach proposed for Canadian ports (Mary R. Brooks Transportation Consulting 2015). Both place a greater emphasis on time-based metrics.

The benefits of extending the existing framework to include more time-based metrics include, but are not limited to:

- allowing for a comprehensive assessment of productivity across the maritime logistics system and identification of actions that can improve the system and inter-port coordination
- helping the many participants of the logistics chain understand the ‘pinch points’ in the system and where they can improve their operations
- assisting government policy and improving strategic planning. Full data is needed to make sure that our ports develop in the best way going forward (recognising that a poor decision today can have significant long-term consequences).

Much of the time-based data is already collected elsewhere but is currently not linked. A time-based recording system already exists for ships. The automatic identification system (AIS) records when ships arrive at a port’s limits, how long they spend at anchorage, the time taken to sail to berth, when the ship is berthed, when it leaves the berth, and when it leaves the port limit. Terminal operators also collect time-related data for their landside operations for their own use. The existing framework could be improved by linking these existing data collections and, potentially, augmenting them.[19]

Not all data would need to be published in *Waterline.* Some could be released in the electronic data tables that accompany the publication. For example, information on underlying distributions could be aggregated for publication (for example, via mean, median and standard deviation statistics). This would also help to maintain presentability and confidentiality. More detailed data could be released in electronic data tables or made available on request.

That said, linking, cleaning and maintaining data is not costless. While much of the data needed to fill the gaps in the framework appear to be collected by participants in the supply chain, there are costs associated with gathering and reporting this data. These costs potentially include, but are not limited to:

- the administrative burden for the participants involved in providing the data (for example, the burden of providing more data for firms with outdated data systems may be too high)
- ensuring confidentiality is maintained and that publishing more data does not facilitate anticompetitive behaviour
- additional governmental resources required (such as setting up contracts to collect data, cleaning and linking the data and reporting and maintaining the data)
- potentially undermining third-party businesses who currently track individual container movements (although, the extended framework focuses on reporting more aggregated statistics rather than container-level data).

[19] Chapter 11 of the inquiry report discusses maritime logistics system data more broadly than the data specifically required for the extended performance framework. It includes a discussion of public and private data sources, data gaps identified by stakeholders, the siloing of data and the role for government in sharing data.

While richer data would support deeper insights into port performance, it is unclear if the associated benefits would outweigh the potential costs inherent in extending the existing framework. But as the Commission has previously noted:

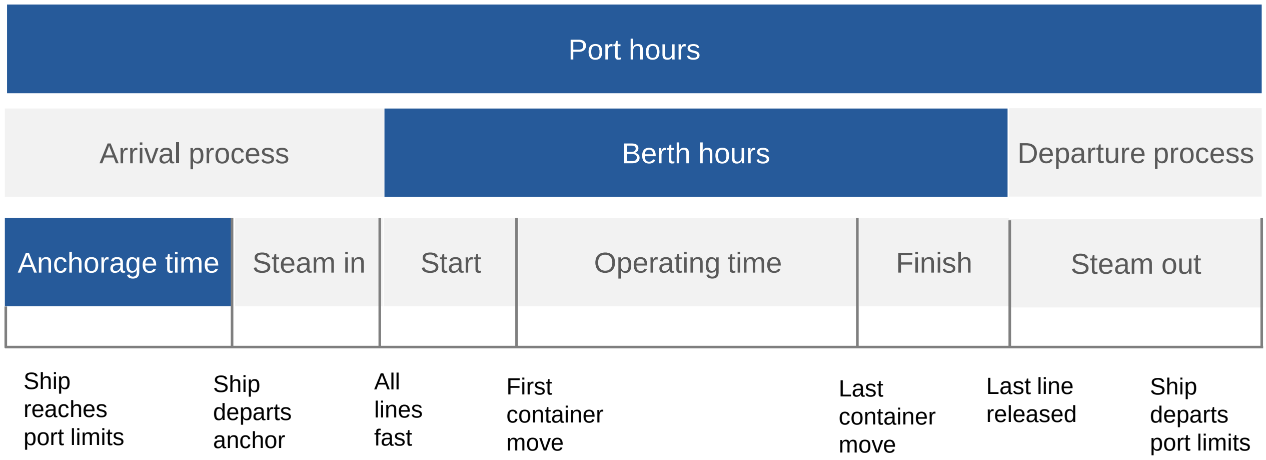
> … the substantive argument for making data more available is that opportunities to use it are largely unknown until the data sources themselves are better known, and until data users have been able to undertake discovery of data. (PC 2017, p. 2)

Further, some of the gaps identified are easier to fill. For example, labour productivity measures or container dwell times could be sourced from container terminal operators, who already provide other related information for publication in *Waterline*. This suggests there is ‘low-hanging fruit’ that could fill some of the gaps in the existing framework in a valuable way. More detailed data on time-based metrics, especially data disaggregated by ship and call size, may be more costly to gather and report.

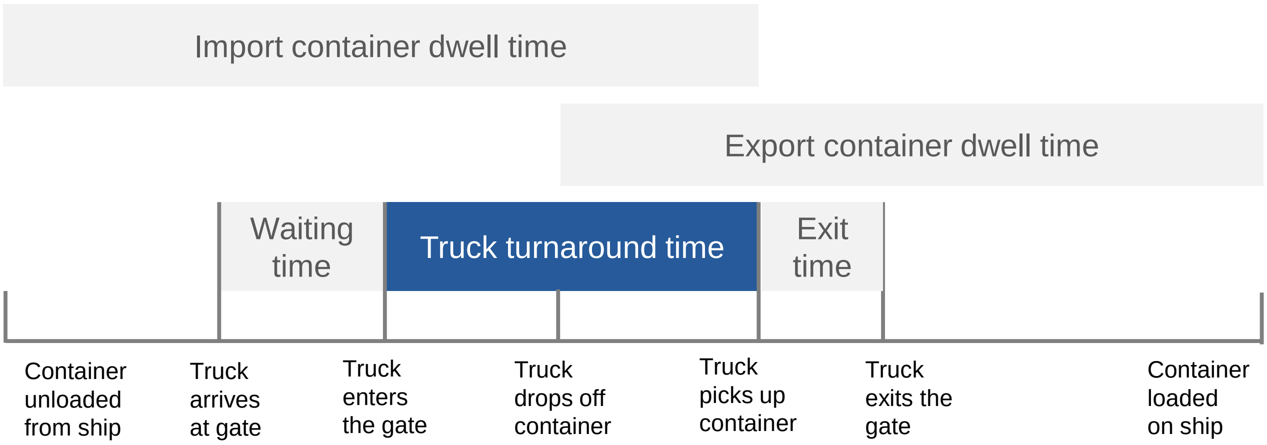
While participants did not provide any indication of the size of the costs or benefits, some provided views. The Australian Chamber of Commerce and Industry (sub. DR133, p. 6) stated that the benefits would ‘greatly outweigh the costs’. The Port of Melbourne (sub. DR123, p. 10) were unclear if the benefits would outweigh the costs, however, they were willing to explore the possibility of filling data gaps further. The Maritime Union of Australia (sub. DR143, p. 33) submitted that data could be voluntarily provided by the holders provided it is cost effective for them. Further, AI Group (sub. DR98, p. 3) noted that ‘port performance data is available in other international markets — such as Europe — without posing competition concerns’.

Figure 2 – Gaps in existing time based measures[a,b]

a) Marineside operations and quayside time-based framework



b) Landside time-based framework



a. The blue boxes indicate that the time-based metric (or some form of it) is available in BITRE's *Waterline* publication. A grey box indicates that data is currently unavailable. **b.** Containers can also be transported via trains. This is not depicted in the figure.

Other data issues in the existing framework

Lack of recent information

Waterline has a long publication lag. For example, *Waterline 67* was released in December 2021 and contained quarterly data up to December 2020. This means that any productivity analysis uses data that is at least a year old. The delay in releasing government data is an issue identified for most freight datasets (iMove Australia 2019, p. 4).

Releasing electronic data tables online, perhaps prior to releasing the *Waterline* publication, could improve the timeliness of data. The New Zealand port performance data is published online enabling access to more recent data for users (Ministry of Transport 2021).

Limited time-series data

Despite having been published since July 1994, *Waterline* contains limited time-series data. This is because the range of reported metrics has expanded over time (which limits time-series data for newer measures) and because some metrics have been renamed and refined (so are no longer consistent over time).

The duration of time series data varies by metric. The crane rate, elapsed labour rate and ship rate span the longest period (1989–2020), enabling a longer-term assessment of quayside productivity. Other measures have much shorter time series which limit their usefulness for examining long-term trends. For example, metrics such as truck turnaround time, anchorage time and ship turnaround time only span 2011–2020.

The limited time-series data makes it difficult to analyse long-term trends in port performance as directed by the terms of reference.

The proposed way forward for assessing port performance

The range of time-based metrics (in figure 2) could be collected, assessed and potentially combined into an index of Australian port performance. The index could build upon the work done by the World Bank (2021) and could be used to compare ports on the basis of container movement times (that is, from arrival on ship to departure on transport for imports and vice versa for exports).[20] This index should incorporate time-based metrics from marineside, quayside and landside operations and, importantly, these time components should be able to be disaggregated into subcomponents (such as anchorage, operating time and container dwell time).

Comparing performance in different time metrics across ports should reveal operations in a port that are relatively inefficient compared with other ports. Other metrics of performance could be used to help to understand *why* these relative inefficiencies are present. For example, analysing crane rates can shed light on operating times: more productive cranes should result in faster times. Unpacking any index and understanding *which* components are inefficient and *why* there are differences in performance can provide more value than the index itself. This is because the process sheds light on specific inefficient areas and potential ways to improve performance.

Such an index should be feasible for Australian ports *if* gaps in the existing data can be filled.

Developing such an index to use in international comparisons would be more challenging. Collecting data on the landside would be more difficult than collecting data for the quayside because landside operations are more fragmented (more operators and different transport types). Given this, the World Bank and IHS Markit's CPPI have made an impressive first pass at collecting time-based metrics for marineside and quayside operations and at constructing a performance index based on these metrics.

This type of performance benchmarking and detailed unpacking of the index could shed new light on port inefficiencies. The analysis may not reveal any role for government intervention. For example, inefficiencies in loading and unloading containers would be an issue for terminal operators to directly address. That said, there may be a role for regulators or governments in setting performance benchmarks.

Given BITRE are the main data collectors and have already undertaken benchmarking exercises in the past (BITRE 2009), they would be well placed to perform a benchmarking analysis. BITRE's *Waterline* data provides a starting point for domestic benchmarking, while international benchmarking could be undertaken if international data sources, such as the Port Performance Program, were obtained. Consultation with industry following the analysis could help to unpack the findings of the benchmarking exercise and help identify ways to improve performance.

Most participants did not comment directly on the proposed index method but were overwhelmingly supportive of the Commission's findings in relation to the filling of data gaps and enhancing the existing performance framework (ACCC. sub. DR92, p. 1; CTA, sub. DR137, p. 2; GrainGrowers, sub. DR121, p. 2;

[20] Ideally the index would also incorporate information about the distribution of these times. Doing so would capture an element of how dependable the port system is. For example, a port with fast container turnaround times with a narrow distribution would be both highly efficient and dependable.

GTA and AGEC, sub. DR91, p. 2; ITF, sub. DR129, p. 8; MUA, sub. DR143, pp. 33, 35-37; NatRoad, sub. DR106; pp. 3–4; NSW Government, sub. DR142, p. 5; NSW Ports, sub. DR141, p. 1; Port of Newcastle, sub. DR108, p. 17; Ports Australia, sub. DR86, p. 1; Shipping Australia, sub. DR114, p. 2; Victorian Government, sub. DR138, p. 1).

Some participants qualified that the extended port performance framework needs to:

- close substantial information gaps (AFGC, sub. DR111, p. 5)
- have a nominated government agency or organisation that has the resources and appropriate mandate to collect and report the data in a timely manner (MUA, sub. DR143, pp. 33, 37)
- produce metrics and insights over time that lead to the identification of inefficiencies and measures that can deliver improvements in port performance (MUA, sub. DR143, p. 33; Tasmanian Government, sub. DR113, p. 6)
- pass a cost benefit analysis (GTA and AGEC, sub. DR91, p. 2).

An opposing view was expressed by DP World (sub. DR140, pp. 2,16) who questioned the need for further benchmarking or data collection from a competitive industry citing it as ‘unnecessary, costly and [that it] risks distorting investment signals’ (p. 2).

Nevertheless, there are several initiatives underway to improve the existing port performance framework. Ports Australia (sub. DR86, p. 1) has commenced a project with the Department of Infrastructure, Transport, Regional Development, Communications and the Arts (DITRDCA) and BITRE to identify productivity measures that better reflect port efficiency with close engagement from industry and government. The Department of Transport (Vic) has also developed a Voluntary Performance Monitoring Framework dashboard which aims to develop performance indicators in relation to the landside container supply chain (DOT 2022).[21] Similarly, Patrick announced it will voluntarily commence publishing quarterly landside performance metrics for Sydney, Melbourne, Brisbane and Fremantle (Patrick Terminals 2022). Meanwhile, the National Freight Data Hub development is underway to improve performance monitoring of freight supply chains (chapter 11). The Commission welcomes the development of these initiatives.

6. How productive are Australian container ports?

In order to assess the performance of Australian ports, the Commission has combined metrics from *Waterline* and IHS Markit’s Port Performance Program.

The Port Performance Program data help to fill some of the gaps in the existing framework and provide a wider range of metrics. In particular, the advantages of this data is that it:

- provides comprehensive information on ship-visit times
- provides terminal operator data
- contains gross measures of productivity
- enables greater consistency with the international comparisons of container port productivity (section 7).

Combining data sources allows for more comprehensive and in-depth analysis of the performance of Australian ports than would otherwise be possible. The Port Performance Program data enables a thorough assessment of time-based metrics on the marineside and quayside and *Waterline* data enables the assessment of landside metrics. Still, gaps in the data means that a performance benchmarking index of the time it takes to move a container through a port (as described above) cannot be constructed. Missing data,

[21] The landside metrics released cover many of the metrics in *Waterline* but have two main advantages: the reporting of terminal level performance (rather than port level) and monthly averages (rather than quarterly).

for example, on container dwell times, means that a significant part of the time that a container spends in port would be missing, potentially biasing the index. Instead, the Commission has sought to benchmark components of time for which data is available and unpack the reasons for relative performance where possible using other performance metrics.

Some participants raised concerns about the use of the Port Performance Program data (DP World, sub. DR140, p. 2; NSW Ports, sub. DR141, pp. 9–10). There were concerns that the data relied on information from ten of the world's largest shipping lines and therefore does not cover every single ship visit to Australian ports.

Using sample data is common in quantitative work. Population data is rarely obtained, and samples are therefore used to draw inferences about the population. Approximately 80 per cent of ship calls to Australian ports are covered in the Port Performance Program data, suggesting relatively good coverage. More importantly the data seems representative of Australian ports. Average call sizes and median ship turnaround times are strikingly similar to those presented in *Waterline* (see appendix A, for more detail).

As with any dataset, the Port Performance Program data is not without issues. There is missing data for some key variables. For example, for a given ship call there may be missing data regarding anchorage times, operating times or gross crane hours. Therefore, any analysis of these variables will rely on a smaller, perhaps less representative, sample. There also appears to be some issues with the attribution of anchorage and steam-in times for some observations and/or ports. The Commission notes that this dataset is in the early stages of development and further data issues are noted throughout the following analysis to flag where some caution is needed in interpreting results.

COVID-19 pandemic-related supply disruptions have caused major disruptions to international and Australian container shipping markets (inquiry report, chapter 1) and introduced significant volatility into port and ship operations. This is evident in the Port Performance Program data for 2020 and 2021 and *Waterline* data for 2020, and it means that those years are unlikely to be representative of productivity in international container ports, including those in Australia. Given this, the Commission's benchmarking of port performance focuses on the 2019 calendar year as it preceded the COVID-19 pandemic and ships were still mostly arriving on schedule. The year 2019 is, therefore, more representative of a 'typical' year.

That said, while in many ways the data for 2019 can be considered representative of earlier years and consistent with longer-run trends, this may not be the case for every port or container terminal operator. For example, negotiations for new enterprise agreements began in late 2018, lasting through to 2022. The nature, type and duration of protected industrial action undertaken as part of these negotiations means that individual terminal operators may have been affected by stoppages and other actions that reduced their throughput and impeded efficient port operations (chapter 9, inquiry report).). For example, NSW Ports (sub. DR141, p. 10) noted that there was industrial action in Port Botany over 2019-20. Events of this type will affect how Australian ports compare, both with each other and international ports.

The following sections assess:

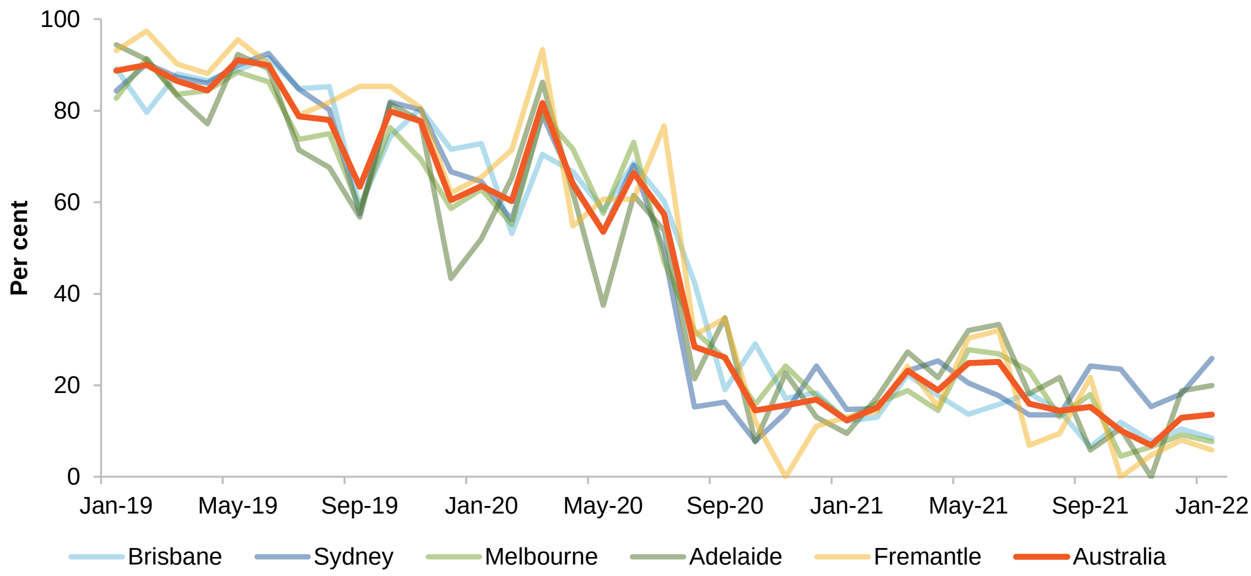
- the reliability of ships arriving at Australian ports on schedule (and thus containers arriving on schedule)
- the productivity of ports (including marineside, quayside and landside operations) in moving those containers through the port.

Service dependability has declined markedly over the past three years

Ships missing windows clearly became a significant problem worldwide following the onset of the COVID-19 pandemic. The trend appears to have started in mid-2019 in Australia and was exacerbated by the COVID-19 pandemic (figure 3). The Maritime Union of Australia (sub. 72, p. 1) stated that 'over the 18 months from August 2020 to January 2022, 83 per cent of all the international container vessels arriving in Australia's five major container ports arrived late for their allocated slot'. Ships were between 5–8 days late in calling at Australian ports in January 2022 (p. 2). DP World (pers. comm., 12 December 2022) commented that ship window reliability has recently improved and is expected to continue improving due to spare capacity in the system.

Figure 3 – Reliability of ships arriving on schedule has declined markedly

Proportion of container ships arriving on time, 2019–2022



Source: Maritime Union Australia (sub. 72, p. 1).

As described above, ships arriving off schedule can give rise to several issues. First, terminal operators must be flexible and alter operations (such as allocating labour) to deal with late arrivals. Second, these ships must wait for the next available berth or until labour is available which may result in longer anchorage times recorded at the port which is not necessarily reflective of inefficient port operations. Third, given ships typically visit multiple Australian ports, the effects of ships arriving off schedule cascades through to subsequent ports, creating a perception of inefficiency across ports. Knowing when and why ships miss their windows would provide important context for interpreting port productivity measures.

Unfortunately, detailed data on shipping schedules and windows is not publicly available. Neither *Waterline* nor the Port Performance Program contain data on the extent to which ships meet their designated windows. The Maritime Union of Australia relied on data from Sea-Intelligence which is not publicly available. Public access to data on shipping schedules and movements would enable an assessment of short- or long-term trends in the dependability of ships servicing Australian ports.

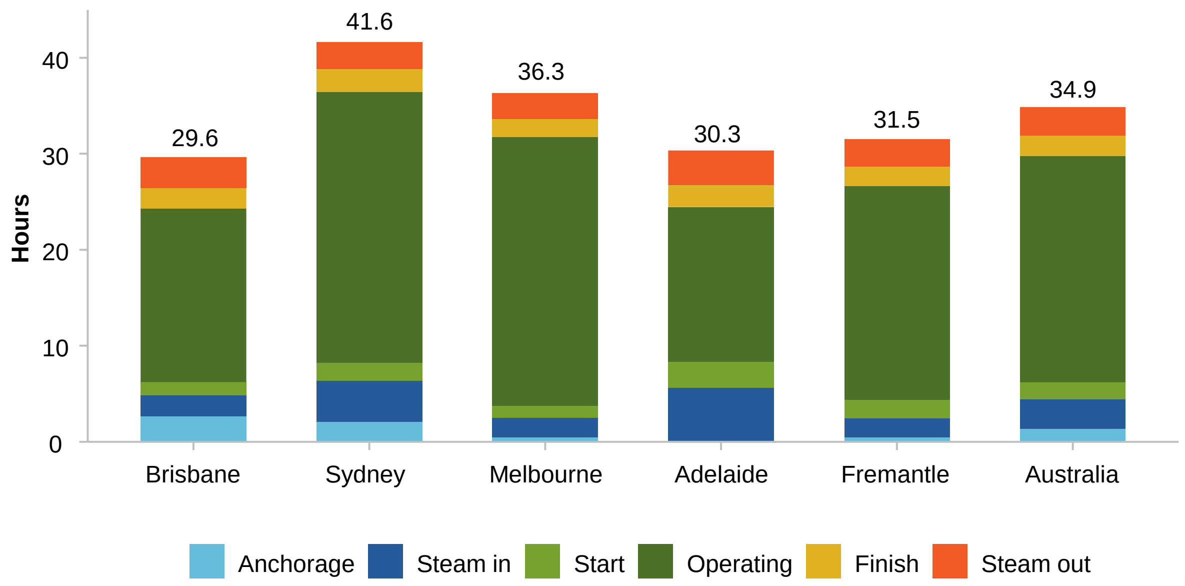
Marineside operations

The productivity of marineside operations is reflected in the time it takes for ships to get into and out of port — ship turnaround time (or port hours). Because container handling is a large part of the time a ship spends in port, quayside operations time is also included in this discussion (and detail about quayside performance is presented in the following section).

On average, each visiting container ship spent 35 hours in Australia's major container ports in 2019 (figure 4). Over three-quarters of this time was spent at berth (27 hours) and two-thirds was taken up with container handling (24 hours). But there is substantial variation in average ship visit times between ports.

Figure 4 – The average container ship spent 35 hours in port[a,b]

Total port hours by component, 2019



a. Observations with arrival hours greater than 72 hours are removed from sample data cleaning advice provided by IHS Markit. Observations with data on all time-based metrics are included in the sample, 85 per cent of full sample.
b. There are some concerns about the anchorage and steam-in times reported for Sydney. These concerns are described in detail in the text below. Appendix A provides a comparison of the port hours from the Port Performance Program data and *Waterline* data.

Source: IHS Markit's Port Performance Program data.

The remainder of the section unpacks port performance in each component of port hours.

When interpreting the following results, it is important to bear in mind that there is sometimes a trade-off between the speed of operations and safety. For example, increasing the speed of straddle carrier cranes may result in higher productivity but also increases the risk of cranes tipping over. Similarly, increasing the speed of a ship entering a port may compromise the safety of tug operators. As noted in chapter 1, efficiency does not necessarily mean having to perform operations faster. Efficiency, interpreted in this technical paper as technical efficiency, is about how inputs are used to produce output. Time is one input and wasted time can be an indicator of an inefficient operation. Nevertheless, safety should not be compromised for faster operations.

Australian ports are relatively safe. The Maritime Union of Australia (sub. 59, pp. 104–105) stated that there has not been a stevedoring fatality on Australian ports since May 2014, nor have inquiry participants raised concerns about serious injuries or accidents in Australian ports. This contrasts with the experience of New Zealand where the Port of Auckland had two fatalities in two recent years (MUNZ, sub. 30, pp. 3–5).

The guidelines and regulations that ensure the safety of Australian workers should not be compromised for speed. The Maritime Union of New Zealand (sub. 30, p. 2) cautioned that when long-standing work practices that ensured the safety of employees were removed, 'productivity of the port may have improved, [but] anticipated direct safety consequences followed'.

Notwithstanding this, the analysis below sheds light on components of port operations that are slowing ship turnaround times and points to areas that could be investigated to determine whether times could be improved without compromising worker safety.

Arrival and departure processes

Arrival and departure processes accounted for about 20 per cent of port hours on average. Reducing anchorage time would be a key way to improve performance, whereas steam-in and steam-out times are likely more difficult to reduce because they should only reflect the sailing of ships within a port.

Anchorage time

As noted above, the time that ships spend at anchorage is wasted time.[22]

Ships spent an average of 1.3 hours (interpreted as 1 hour and 18 minutes) at anchorage in 2019, with Brisbane and Sydney having the highest average anchorage times (2.6 hours and 2.1 hours, respectively) (figure 4). These times are averages across all vessels and, as such, may be skewed both by ships that steam straight in and by outliers that have to wait much longer than other ships. Consistent with this, average wait times are higher when ships that did not anchor are excluded, and median anchorage times are considerably lower than average times for vessels that did anchor.[23]

These averages mask variations across terminal operators and over time (figure 5). For example, anchorage times increased for ships using all three Sydney terminal operators from September quarter 2018 through to the end of 2020. A number of factors could have contributed to this increase, including:

- intense storms — October 2018 included seven days where waves were above 3 meters in Sydney, including three consecutive days. Significant wave events were further experienced in June 2019 (Manly Hydraulics Institution 2020, fig. 5.15). This can create unsafe conditions for pilotage forcing ships to anchor rather than enter port
- industrial action — there were industrial disputes at DP World and Hutchison (ACCC 2019, p. 24)
- the increase in ships arriving off schedule (figure 3).

The average anchorage time returned to below September quarter 2017 levels by June quarter 2020, only to then rise sharply again due to the COVID-19 pandemic and subsequent industrial action (NSW Ports 2020).

[22] Anchorage time in the Port Performance Program data is defined as the total elapsed time from when a ship enters an anchorage zone to when it departs the anchorage zone (and ship speed must have dropped below 0.5 knots for at least 15 minutes within the zone). Some ports, such as Adelaide and Sydney, do not have designated anchorage zones, but IHS assigns zones in order to be able to capture the time between when a ship arrives at a port and when it berths.
[23] In 2019, 93 per cent of ships anchored in Brisbane. These vessels waited an average of 3 hours (median 2.1). For Sydney, almost 50 per cent of ships anchored. These vessels waited an average of 4.3 hours (median 1.9). In contrast, only 3 per cent of ships anchored in Melbourne but they waited 13 hours on average (median 9 hours).

The data suggest productivity improvements could be made in Sydney and Brisbane by reducing anchorage time to the extent that the reason for anchorage is not due to external factors (such as ships arriving off-schedule or poor weather conditions).[24]

Steam-in and stream-out times

Steam-in time should reflect the movement of a ship from either the port limits or anchorage to the berth. Similarly, steam-out time reflects movement from the berth to port limits. Some anchorages are located further away from the berth and therefore steam-in and steam-out times are expected to be larger for these ports. Factors such as sailing speed will also affect these times.

Steam-out times were similar across ports, but steam-in times differed (figure 4). Steam out times averaged 3 hours, with the longest average time recorded in Adelaide (3.6 hours) and the shortest in Melbourne (2.8 hours). Steam-in times were highest in Adelaide (5.6 hours) and Sydney (4.3 hours) compared with other ports (2.1 hours on average). NSW Ports (sub. DR141, p. 7) noted that their records show that steam-in times in Sydney 'are on average 1-1.5 hours, by far the shortest of the three east-coast container ports' and as such 'there is clearly an issue with the data'. Higher steam-in times in Sydney and Adelaide appear to be due to data issues.

- For Adelaide, the Port Performance Program data suggest that no ships anchored but the *Waterline* data indicate that they did. Because anchorage could not be distinguished from steam-in time in the 2019 Port Performance Program data, steam-in time was inflated by the inclusion of anchorage time. Data for 2021 contain both anchorage and steam-in time and revealed that average anchorage time in Adelaide was 4 hours and steam-in time was 2.6 hours.
- For Sydney, some ships crossed an anchorage zone assigned to Sydney and then left the zone to wait somewhere outside Sydney harbour before finally berthing after an extended wait. The additional waiting time was captured in steam-in time rather than anchorage time (Turloch Mooney, IHS Markit, pers. comm., 11 May 2022). Therefore, average steam-in time is inflated and it is likely that average anchorage time is understated.[25]

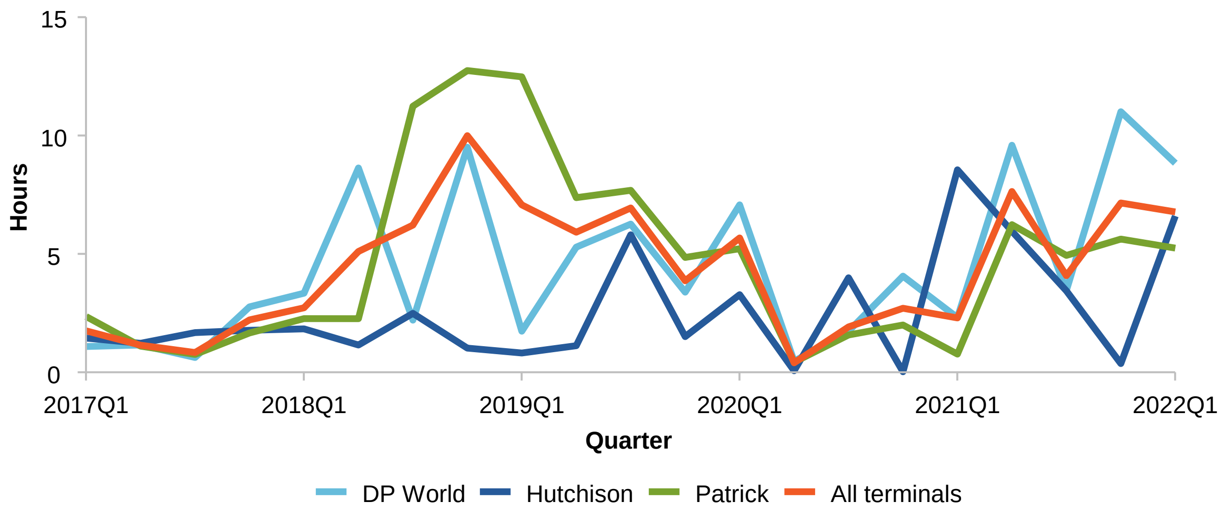
Given the data issues for steam-in times for some Australian ports and because steam-in times are unlikely to be an area where productivity gains can be made (that is, these times should only reflect sailing), the Commission does not place emphasis on these results.

[24] The *Waterline* data also show longer average anchorage times in Sydney and Brisbane in 2019 (BITRE 2022). In Sydney, about 1 in 5 ships anchored for more than 2 hours; these ships waited for an average of 18 hours. In Brisbane, about 1 in 10 ships anchored for more than 2 hours; these ships waited for an average of 18 hours.

[25] This contributed to data observations with unreasonably high steam-in times in Sydney. NSW Ports (sub. DR141, p. 7) noted that due to different geography of ports and boundaries on port limits, steam-in times are not being measured consistently across ports, which also complicates the comparison of steam-in times.

Figure 5 – Average anchorage hours in Sydney[a,b]

Average anchorage hours in Sydney by terminal operator, 2017–2022



Source: IHS Markit's Port Performance Program data.

Berth hours

Berth hours account for almost 80 per cent of port hours on average and encompass start and finish times, and operating time. Improving performance in these time components could help to turn ships around faster. This is especially true for cargo operations which account for the bulk of a ship's time spent in port.

Importantly, giving terminal operators access to a ship once it has berthed allows them to start container handling operations as soon as possible. Terminal operators are not able to unload containers until the ship or its cargo have undergone a clearance procedure or before containers are unlashed by dock workers. If ships are sitting idle with no work being carried out, then this idle time is wasted and reduces port productivity. On average, ships were available to terminal operators (stevedores) for 86 per cent of the time that they were berthed in 2019 (figure 6). Cranes operated for 65 per cent of total berth hours.

Start and finish times

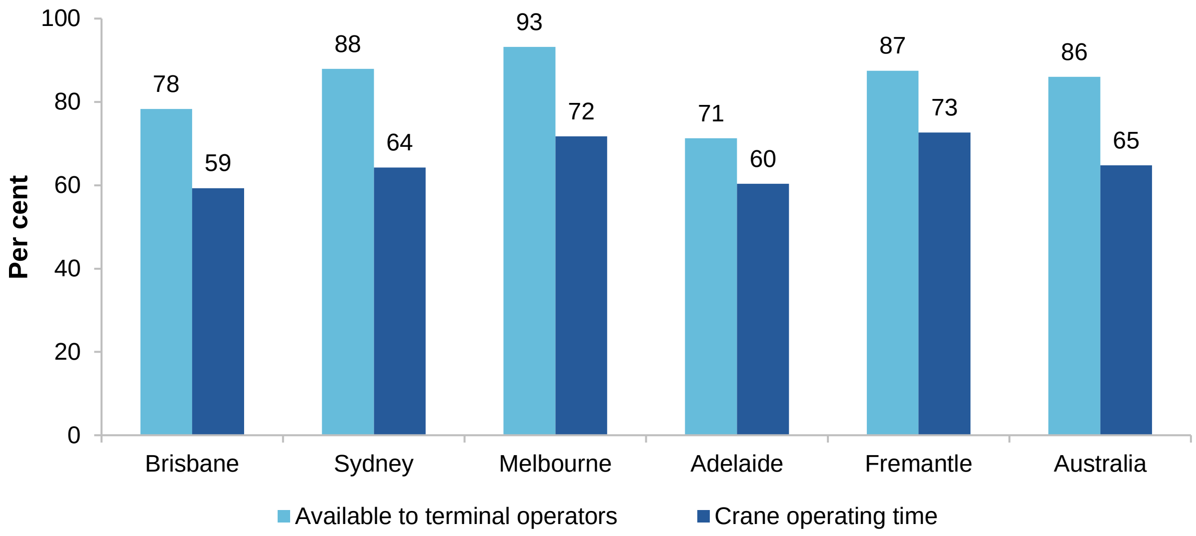
The average time taken between when a ship arrived at berth (all lines fast) and when cargo operations started (first lift) varied across ports (figure 4). Adelaide had the longest start time on average (2.7 hours), while Melbourne had the fastest (1.3 hours on average).

Finish time, that is, the time taken from when cargo operations finished (last lift) to when the ship was ready to leave (last line released), was more similar across ports. Sydney had the slowest finish time on average (2.4 hours), while Melbourne had the fastest (1.8 hours).

When start and finish times are combined, Adelaide has the slowest time on average (5 hours), followed by Sydney (4.3 hours) and Fremantle (4 hours). Melbourne and Brisbane were the fastest (3.1 and 3.5 hours respectively). This suggests that Adelaide, Sydney and Fremantle may have scope to improve start and finish times to lower their berth hours. NSW Ports (sub. DR141, p. 6) noted that sometimes shipping lines request to remain at berth for longer periods than required to service the ship due to off-schedule arrivals or delays at the next port. If these requests are granted, then start and finish times may be inflated. These types of requests cannot be discerned in the data; however, the distribution of start and finish times is similar across Australian ports suggesting that making comparisons across them is justified.

Figure 6 – Terminal operators had greater access to ships in Melbourne[a]

Share of total berth hours where ships were available to terminal operators and cranes were operating, 2019



a. Available to terminal operators means the total time ship available to stevedores divided by total berth hours. Crane operating time: total operating hours divided by total berth hours.

Source: BITRE (2021).

Operating time

Operating time is the largest single component of port hours (figure 4). On average, operating time accounts for almost 68 per cent of port hours. Adelaide had the shortest average operating time at 16 hours and Sydney and Melbourne had the longest (about 28 hours each) (table 5).

Operating time is influenced by a range of factors, including:

- call size (that is, the number of containers unloaded and loaded on each ship visit)
- the number of quay cranes used to handle containers and the productivity of those cranes (discussed in more detail below).

Larger call sizes will typically require longer operating hours because there are more containers to be handled. Differences in average operating times between the Australian ports largely reflect differences in average call sizes. The ports with higher average call sizes — Melbourne and Sydney — had the longest average operating time per ship (table 5). The performance differential is less pronounced once call size is taken into consideration — that is, differences in operating minutes per move are considerably smaller than those in average operating times.

Table 5 – Average operating time related to call size, 2019[a]

Port	Total calls	Total moves	Average call size	Total operating time	Average operating time	Operating minutes per move
	no.	no.	no.	hours	hours/ship	min
Brisbane	620	541 797	874	11 225	18.1	1.24
Sydney	719	1 060 157	1 474	20 260	28.2	1.15
Melbourne	652	1 125 798	1 727	18 223	27.9	0.97
Adelaide	309	225 565	730	4 974	16.1	1.32
Fremantle	341	371 826	1 090	7 595	22.3	1.23
Australia	2 641	3 325 143	1 259	62 276	23.6	1.12

a. Observations with data on all time-based metrics are included in the sample, 85 per cent of full sample.

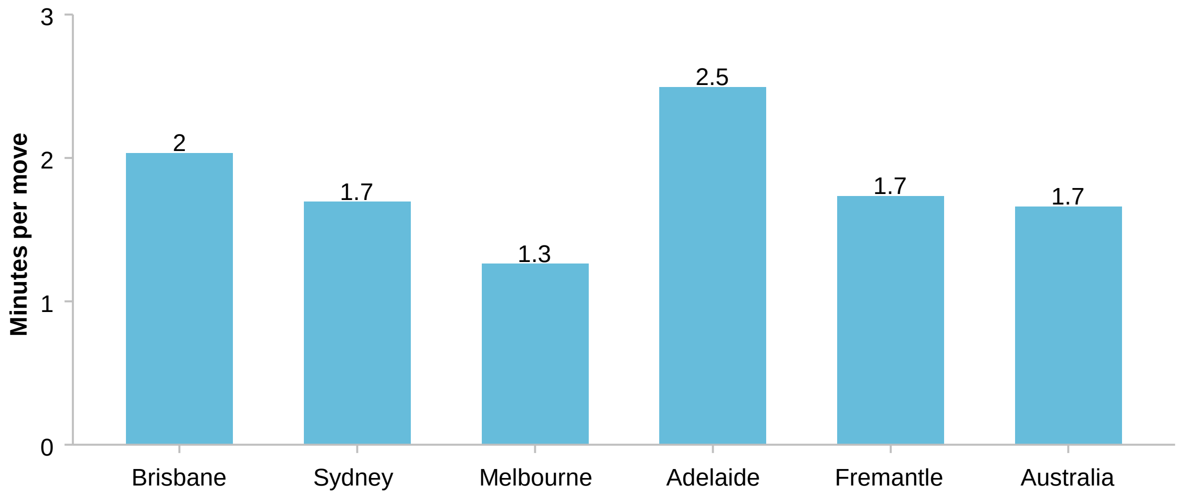
Source: IHS Markit's Port Performance Program data.

The number of cranes allocated to ships also influences operating times. More cranes (within the physical restrictions of the ship and berth) will enable more containers to be moved simultaneously. The number of cranes deployed will typically be higher for larger call sizes. Melbourne and Sydney deploy more cranes per ship (discussed below). As a result, these ports recorded faster average container moves. Adelaide, with the smallest average call size, had the longest average handling time at 1.3 operating minutes per container move (table 5).

Moreover, larger ships typically involve larger call sizes, and larger ships therefore generally result in lower minutes per container moved (port hours per move). Sydney and Brisbane handle more smaller ships and call sizes than Melbourne, helping to explain why their average time taken to handle a container is higher than Melbourne's (figure 7). Melbourne's lower anchorage times also contributes to this outcome.

Figure 7 – Ships in Melbourne spend less time in port per container

Total port hours per container move, 2019



Source: IHS Markit's Port Performance Program data.

Quayside operations

Quayside productivity captures the efficiency of moving containers from or onto ships using quay cranes. It also includes any incidental container movements, such as re-stowing cargo for unloading at later ports.

A more productive quayside results in fewer minutes per container move and faster cargo operation times for a given call size. This can help to turn ships around faster, especially given cargo operations account for the bulk of a ship's time in port.

The time taken to unload and load a ship depends, among other things, on:

- the number of quay cranes working the ship
- the gross productivity of each crane.[26]

This section focuses on two measures of quayside productivity — the crane rate and ship rate. Box 4 presents a numerical example of these measures.

Box 4 – Understanding quayside productivity measures

A simplified numerical example illustrates commonly used quayside productivity measures.

Assume that a typical ship call involves:

- call size = 1000 containers
- total number of cranes allocated = 3
- operating time = 17 hours
- gross crane time = 30 hours (assumes that each crane is allocated to work 10 hours[a])
- crane intensity (average number of cranes working the ship per operating hour) = 1.8 (gross crane time ÷ operating hours[b])
- operational and non-operational delays = 3 hours
- net crane time = 27 hours (gross crane time less operational and non-operational delays).

The following measures are reported in *Waterline*:

- *net crane rate* = call size ÷ net crane time = 37 moves per crane hour
- *net ship rate* = net crane rate x crane intensity = 67 moves per hour.

Measures not published in *Waterline* but are commonly used internationally (JOC Group 2014; World Bank 2021) and that can be calculated using the Port Performance Program data are:

- *gross crane rate* = call size ÷ gross crane time = 33 moves per crane hour
- *gross ship rate* = gross crane rate x crane intensity = 60 moves per hour

a. The data reflects that not all cranes will typically operate for the full operating time. **b.** *Waterline* calculates crane intensity by replacing operating hours with elapsed labour time.

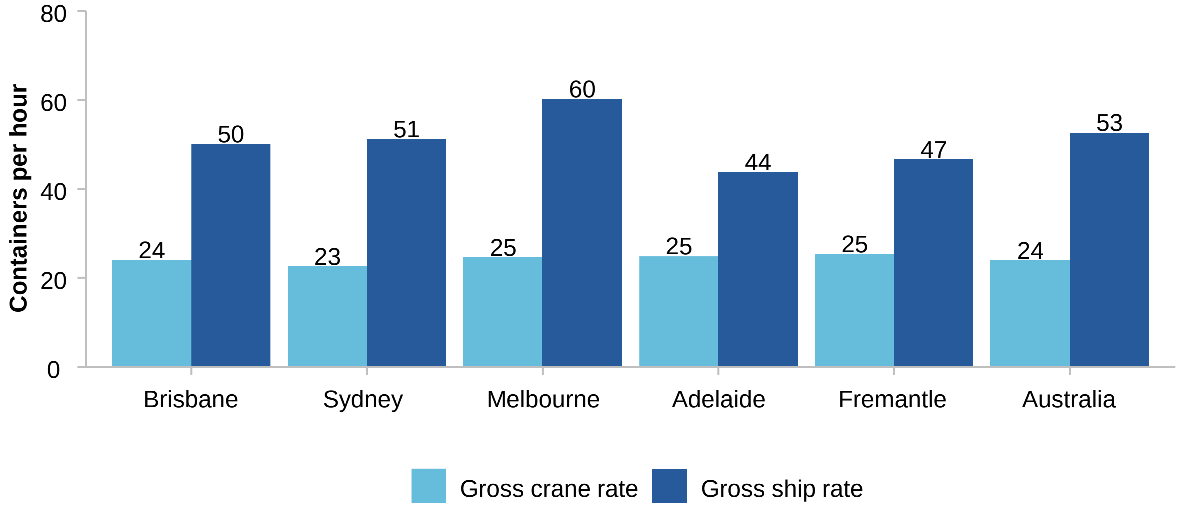
Average crane rates are similar across ports but average ship rates differ (figure 8). Gross crane rates were similar across ports in 2019, with each crane handling an average of 25 container movements per hour. But Melbourne had the highest gross ship rate at 60 moves per hour while Adelaide had the lowest gross ship rate at 44 moves per hour.

[26] The time taken to unload and load a ship will also depend on the extent of operational and non-operational delays if a net crane rate measure is being used.

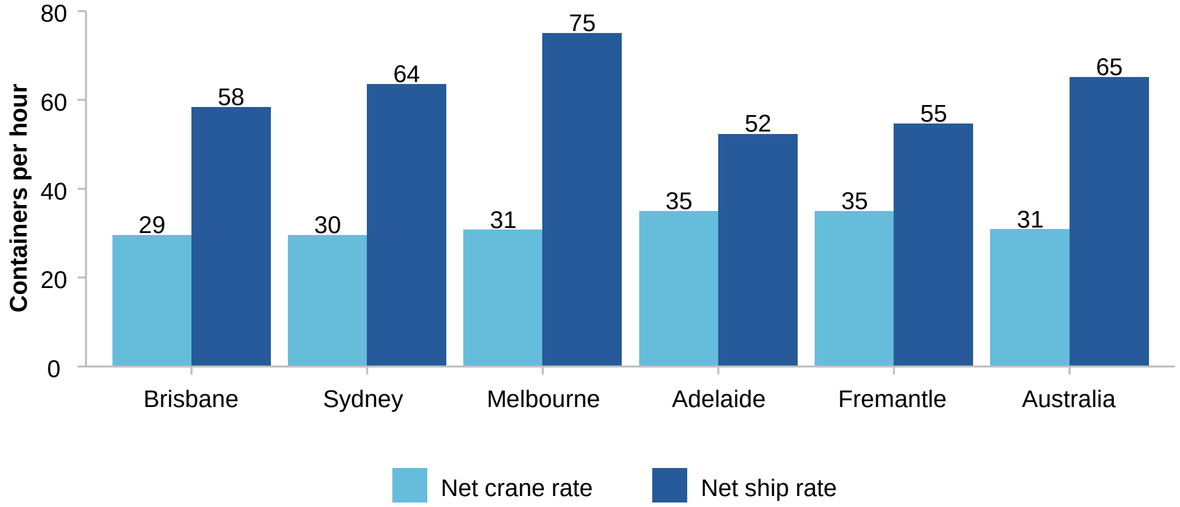
Figure 8 – Fremantle and Adelaide have the highest crane rates; Melbourne and Sydney have the highest ship rates

Quayside productivity, 2019

a) Gross measures



b) Net measures



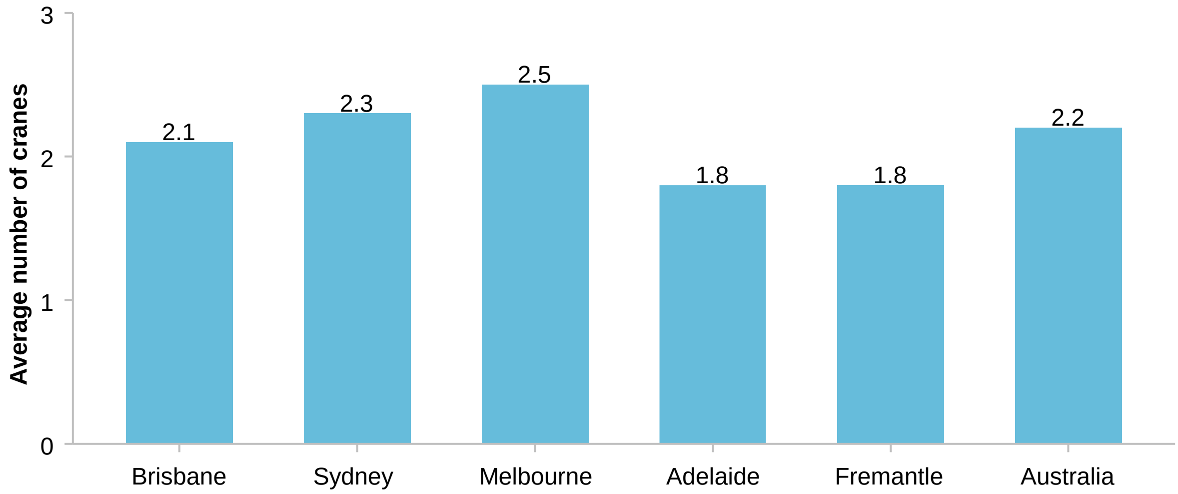
Sources: BITRE (2021) and IHS Markit's Port Performance Program data.

Differences in gross ship rates are explained by the number of quay cranes deployed. The gross ship rate depends on the number of cranes deployed to that task (or crane intensity). For a given level of crane productivity, a port can move more containers in a ship hour if more cranes are allocated to ships. Melbourne and Sydney had higher gross ship rates than the other Australian container ports because they used more cranes per ship on average. Melbourne used 2.5 cranes per ship in 2019 compared to 1.8 in Adelaide and 1.8 in Fremantle (figure 9). This higher average number of cranes meant that Melbourne moved 13 to 16 more containers per hour than did Adelaide and Fremantle despite having similar crane productivity.

Assuming comparability between the Port Performance Program (gross rates) and *Waterline* (net rates) data, differences between the gross (figure 8a) and net rates sheds (figure 8b) light on the extent of operational and non-operational delays. For each port, differences in the two crane rates suggests that delays are reducing crane productivity. For the ship rate, differences are larger. For example, in Melbourne, the gross ship rate is 60 containers, but the net ship rate is 75 containers, suggesting that operational and non-operational delays reduce the number of containers that can be moved in an hour by 15 containers on average.

Figure 9 – Melbourne uses more quay cranes than other ports[a]

Average number of cranes, 2019



a. The average number of cranes (also known as crane intensity) is defined as gross crane hours divided by operating hours.

Source: IHS Markit's Port Performance Program data.

Terminal operator quayside productivity

Port-wide averages do not reveal much about each terminal operator's productivity within a port. The Port Performance Program data enables the assessment of productivity by terminal operator.

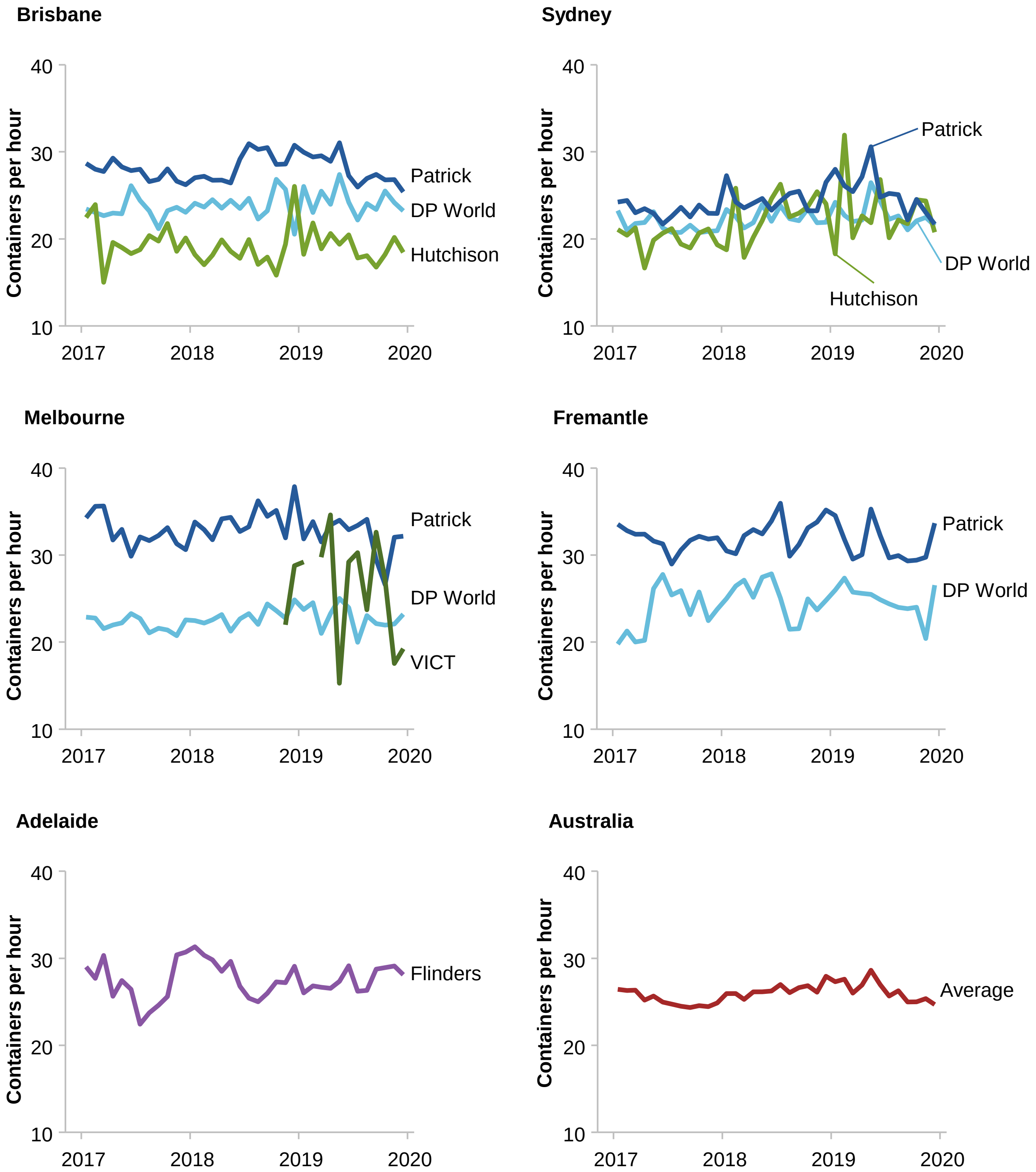
Gross crane productivity varies across terminals within a port (figure 10). Patrick tended to have higher average gross crane rates across all ports between 2017 and 2019, followed by DP World. Newer entrants to the market (such as Hutchison and VICT) tended to have lower or more variable gross crane rates. The exception was Sydney, where gross crane rates converged across the terminal operators in 2019.

Crane rates also vary markedly over time for terminal operators within a given port (figure 10). For example, the average monthly gross crane rate for Patrick in Melbourne between 2017 and 2019 ranged from 27 to 38 container moves per hour, while rates for Hutchison in Sydney ranged from 17 to 32 container moves per hour. Appendix B contains additional figures which highlight the degree of variability in gross crane rates within and across terminal operators for given ship and call sizes.

Evidence of considerable variations in gross crane rates for each terminal operator over time, and between terminal operators requires further consideration. The data prima facie suggests that Australian terminal operators have scope to improve ship turnaround times by improving crane rates without making any changes to the average number of cranes used. However, the extent to which factors inside the terminal operators control affect the variability in gross crane rates will impact the extent to which productivity improvements are possible.

Figure 10 – Productivity varied between terminal operators within ports[a]

Average monthly gross crane rate, 2017–2019



a. The first observation for VICT in Melbourne was in November 2018. The observation for VICT in February 2019 was excluded because it appeared to be an extreme outlier in the series, with an average crane rate of 48 for that month.

Source: IHS Markit’s Port Performance Program data.

Many factors, some inside and some outside of the terminal operator's control, affect quay crane productivity. For example:

- the number of quay cranes and yard cranes operating at a given time. These cranes must work across the quay and yard interface to move containers to and from the ship and into and out of the yard
- the allocation and skill of the crane operator and labour gang
- the types of quay cranes used (such as their age, size, ability to handle two containers)
- the design of the yard (such as the size, configuration and the equipment used)
- the size of ships visiting and the stowage pattern of containers onboard
- whether any protected or unprotected industrial action is taking place (such as a stoppage or go-slow)
- weather conditions (which help govern how fast a container can be moved)
- the type of technology used across the port.

Regardless of the technology used, terminal operators have an incentive to utilise their cranes as efficiently as possible. Higher rates of crane productivity imply higher rates of asset utilisation. Given the substantial fixed costs involved in purchasing quay cranes, the cost per container moved declines as the number of containers handled by a crane increases (referred to as 'economies of scale'). The irregular nature of ship arrivals and variations in call sizes that are outside the control of terminal operators mean that achieving high rates of crane utilisation may not always be possible. This observation also applies to other assets such as berths and, on the landside, container yard area. One downside to high capital utilisation is that there may be limited capacity to handle any future growth in throughput without further investment.

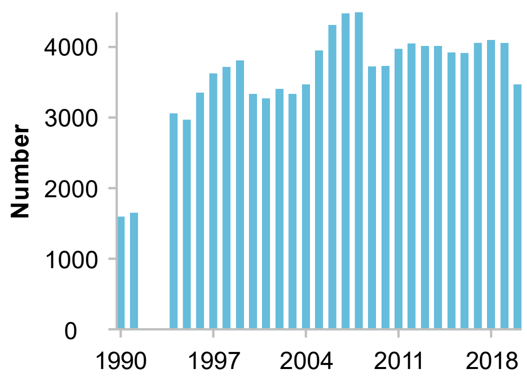
Long-term quayside productivity trends

The number of ships handled at Australian ports has increased over the long term as has the volume of cargo handled (figure 11). The number of container ships visiting Australia annually has been relatively stable since about 2011. However, the number of containers handled has continued to grow. This has meant that the average call size — the average number of containers handled per ship visit — has increased. Australian ports are not only handling bigger ships (chapter 7, inquiry report) but they have relatively more cargo to unload and load on each visit.

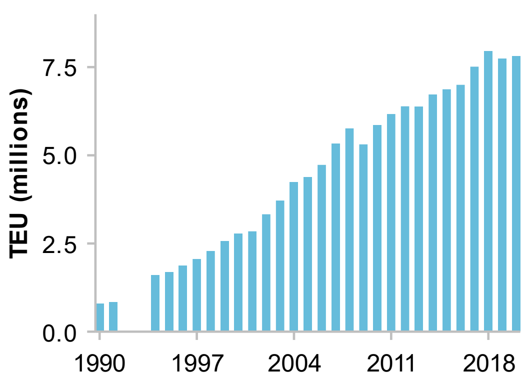
Figure 11 – Australian ports are handling larger call sizes[a]

Annual, 1990 to 2020

a) Container ship visits



b) Throughput



a. Data for 1992 and 1993 are incomplete and therefore not presented.

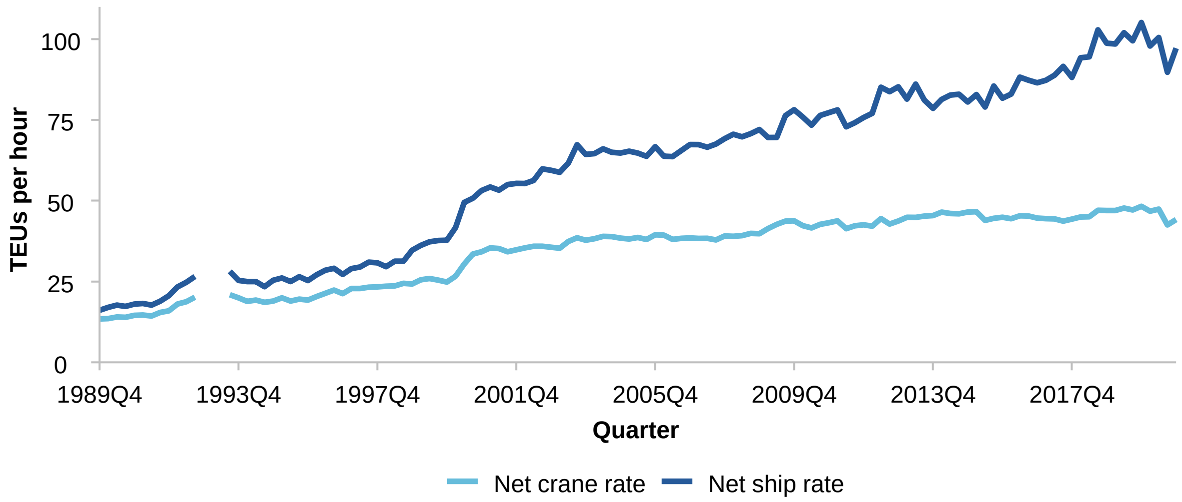
Source: BITRE *Waterline* (various editions).

The productivity of Australian container ports is higher today than it was in the late 1980s (figure 12).[27] For example, the net crane rate rose from 16 containers per hour in 1995 to 30 containers per hour in 2020 (figure 12b). The net ship rate across all Australian ports similarly grew from 21 containers per hour in 1995 to 65 containers per hour in 2020 Higher growth in the net ship rate relative to the net crane rate implies that the average number of cranes used to service a ship increased over the period.

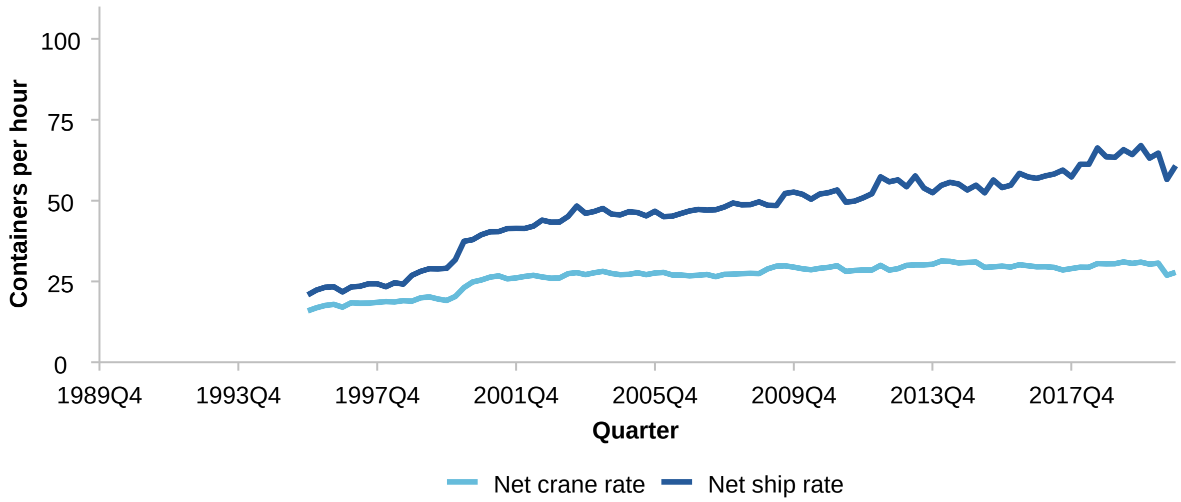
Figure 12 – Long-term productivity has risen in Australian ports[a]

Net crane and ship rates, five-port average, 1989Q4 to 2020Q4

a) TEUs per hour



b) Containers per hour



a. Data for both crane and ship rates in terms of TEUs was not published between 1992Q4 and 1993Q2. Data for both crane and ship rate in terms of containers per hour was not published prior to 1995Q4.

Source: BITRE *Waterline* (various editions).

[27] This result also holds for each port (see technical paper). *Net* rates are presented reflecting the limited long-term data available in *Waterline*.

In part, net crane rates measured in TEUs per hour have improved because cranes are handling larger containers — the number of *TEUs* moved per hour has grown more than the number of *containers* moved per hour since the early 2000s. Movement of one 40-foot container is equivalent to the movement of two TEUs (20-foot equivalent containers), and the share of 40-foot equivalent unit containers has been increasing (for example, from 24 to over 55 per cent between 1997 and 2020). The fact that this increase has not reduced the rate at which quay cranes move containers suggests that these (or newer) cranes have handled the shift to larger containers well. It is also a good indication that ports are handling more goods per container movement than previously — a productivity improvement.

Productivity growth was strongest in the 1990s (table 6). Growth in the net crane rate (containers) averaged 4.1 per cent in the four years to the June quarter 1998. This may have reflected continuing improvements in efficiency related to the 1989–1992 waterfront reforms.[28] Annual growth in the crane rate increased to 20 per cent between June 1998 and June 2001. The increase was due to the 1998 reform package which aimed to improve the efficiency of the waterfront (PC 2003, p. 9). One key objective was a five-port average net crane rate of 25 container movements per hour — a rate achieved for the first time in the December quarter 2000 (PC 2003, p. 12).

Productivity growth has slowed over the last two decades (table 6). But without longer time-series data (of periods that do not reflect the effects of waterfront reforms) one cannot rule out that the more recent growth rates reflect a return to a long-term trend.

Reflecting maritime supply chain issues arising from the effects of the COVID-19 pandemic and industrial action, quarterly productivity growth rates over the last two years have become quite volatile with exaggerated quarterly growth rates (both positive and negative), particularly for net ship rates.

The trends presented here hold for all Australian container ports individually (see appendix B).

Table 6 – Australian port productivity growth has slowed

Five-port average growth rates, selected periods

	Net crane rate		Net ship rate	
	TEUs	Containers	TEUs	Containers
1995 to 1998	5.3%	4.1%	5.5%	4.2%
1998 to 2001	23.3%	19.7%	30.5%	28.1%
2001 to 2010	1.7%	0.8%	3.6%	2.5%
2010 to 2020	1.3%	0.7%	3.2%	2.5%

Source: BITRE *Waterline* (various editions).

Landside operations within ports

Landside operations within ports cover the movement of containers between the base of quay cranes and the port gate (or perimeter). This covers movement through the container yard, temporary storage by terminal operators prior to collection, unloading and loading onto land-based transport (trucks and trains) and the customs and quarantine clearance process.

[28] The three-year program reformed the stevedoring industry with a move from industry-based to company employment, and the creation of career structures in the industry with suitable training and incentive arrangements. An evaluation found efficiency indeed improved (BTCE 1995, p. xviii).

The efficiency of some of these processes cannot be analysed due to a lack of data. For example, there is no information publicly published on container dwell times (as noted above, the time a container spends in port after being discharged from a ship until it leaves the port for delivery to clients), nor is there readily available data on the time it takes for containers to clear customs or quarantine (section 5). In terms of unpublished data, DP World (pers. comm., 27 May 2022) noted that the container dwell times in their Australian terminals are among the best in the world. In 2021, their Australian container dwell times were recorded at two or fewer days, lower than the international median of approximately five days. Flinders Port Holdings (pers. comm., 7 December 2022) recorded import dwell times of three days and export dwell times of about 5 days in Adelaide in 2021.

This section analyses the efficiency of Australia’s major container ports in handling the trucks that drop-off and/or pick-up containers within the port perimeter. Trucks handled the bulk of all landside freight movements to and from Australian container ports in 2019 (chapter 7, inquiry report). Because data on rail is relatively scarce, this section focuses on trucks.

There are some important differences across ports that impact landside productivity, including that:

- land transport (both trucks and trains) is utilised most effectively when it carries containers into and out of a port (referred to as ‘backloading’), as this reduces the number of empty movements
- trains can carry significantly more containers per trip than individual trucks
- trucks are far more flexible than trains, both in terms of their potential turnaround times and where they can go
- trucks are more cost-effective than trains for smaller loads and over shorter distances
- differences in the mix of container movements across ports will affect their landside productivity.

These factors will be discussed where relevant.

Available data do not permit an assessment of long-term trends in landside productivity. Collection of most landside productivity measures in *Waterline* commenced in 2011. This provides roughly nine years of data for analysis when data affected by the COVID-19 pandemic are excluded. While recent trends can be identified, the data do not support long-term productivity analysis. Appendix B presents some time-series charts for a number of landside measures but these are not analysed in detail.

Differences in the landside freight task

There is an important difference in the freight task across Australian container ports that will have important implications for published landside productivity measures. For example, a port with a large trade imbalance (that is, more imports than exports) may struggle to fully utilise and backload trucks.

It is not obvious in the aggregate statistics, but Australian ports handle more full container imports than they do exports — unloading roughly three full containers for every two full containers that they loaded in 2019 (table 7). This imbalance between imports and exports of full containers means that shipping lines need to export empty containers.[29]

This imbalance between full import and export containers, and the subsequent handling of empty containers, is a bigger issue for Sydney than it is for any other Australian port (table 7). Virtually all containers that came into Sydney in 2019 were full (99 per cent), but their share of full exports was lowest at 39 per cent. This means that three in five containers exported from Sydney were empty.

[29] Australia imported few empty containers in 2019.

Table 7 – Australian ports import more full containers than they export[a,b]

Landside throughput ('000 TEUs), 2019

Measure	Brisbane	Sydney	Melbourne	Adelaide	Fremantle	Australia
Imports (TEU)	666	1 293	1 491	215	406	4 072
Exports (TEU)	644	1 279	1 471	200	380	3 974
Total (TEU)	1 310	2 572	2 963	415	786	8 046
Net (TEU)	22	13	20	15	26	98
Import share (%)	50.8	50.3	50.3	51.8	51.7	50.6
Full imports (TEU)	591	1 278	1 354	161	362	3 746
Full import share (%)	88.6	98.9	90.8	74.8	89.1	92.0
Full exports (TEU)	361	498	894	164	261	2 177
Full export share (%)	56.0	38.9	60.8	82.1	68.6	54.8

a. TEU: twenty-foot equivalent containers. **b.** Rounding errors may be present in the table.

Source: BITRE (2021).

Truck turnaround times

Truck turnaround time is the time elapsed from when a truck enters the gate of a container terminal to the time when the last container is loaded onto the truck Lower truck turnaround times are indicative of higher landside productivity. In 2019, Fremantle and Melbourne had the shortest turnaround times, while Sydney and Brisbane had the longest (figure 13). These times are likely influenced by a number of factors such as, the configuration of the port/terminal, the degree of port congestion, how many containers were dropped-off or loaded per visit and the speed of terminal operations in loading containers onto/off trucks.[30] On average truck turnaround times in Australia are 30 minutes. NSW Ports (sub. DR141, p. 8) claimed that a turnaround time of around 30 minutes is 'world class'. DP World (sub. DR140, p. 10) also noted that their Australian terminals performed strongly relative to their international terminals in terms of truck turnaround times.

As noted above, truck turnaround times may appear artificially low if trucks wait outside the port gate until their containers are ready for collection. Given the absence of data on at-gate waiting times, it is not possible to ascertain if, and by how much, this practice affects measured turnaround times.

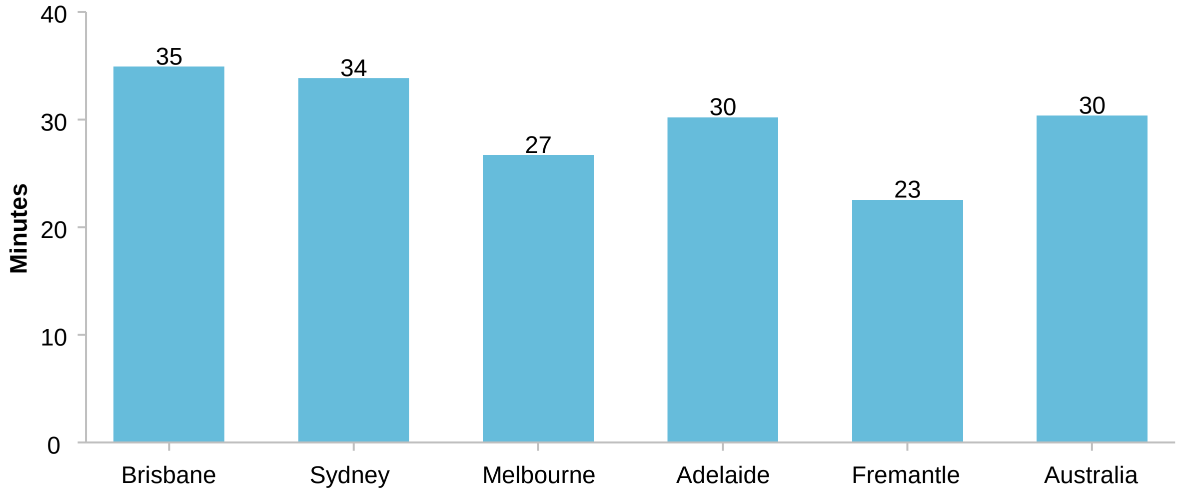
Truck utilisation

Truck utilisation measures the average number of TEUs handled per truck trip. All other things equal, higher utilisation rates are indicative of higher landside productivity because the port is moving more containers per truck trip. Higher productivity vehicles (bigger trucks) (chapter 7, inquiry report) and increased backloading would tend to increase the truck utilisation measure.

[30] NSW Ports (sub. DR141, p. 8) expressed concerns about potential inconsistencies in the way truck turnaround times are measured across ports, but BITRE (pers. comm., 2 December 2022) noted that truck turnaround times in *Waterline* are collected from container terminal operators and are therefore consistently defined as the time from terminal gate entry until last container loaded.

Figure 13 – Landside turnaround times vary by Australian container port[a]

Average truck turnaround time, 2019



a. The average time from when trucks enter the port to when the last container is loaded, and the truck is ready for departure.

Source: BITRE (2021).

Most ports averaged around 2.5 TEUs per truck (equivalent to 1.7 containers per truck). Adelaide recorded the highest rate at 2.7 (figure 14). And the one exception was Sydney, which averaged 2 TEUs per truck. Truck utilisation in Sydney is much lower than the other ports because, as noted above, Sydney has the highest trade imbalance (table 7). A low proportion of *full* export containers reduces the opportunity for backloading because *empty* export containers are typically returned to and handled by empty container parks (ECP) rather than port terminals. These containers do not count towards the truck utilisation figures presented in *Waterline* because they are not processed through the VBS/TAS systems located at terminals. As such, actual truck utilisation may be higher (that is, a truck might take empty containers to ECPs on the inbound trip and collect imported containers from the terminal on the outbound trip). NSW Ports (sub. DR141, p. 2) noted that 'truck utilisation analysis… requires triangulation of data between empty container parks and stevedore terminals — which is not presently available'.

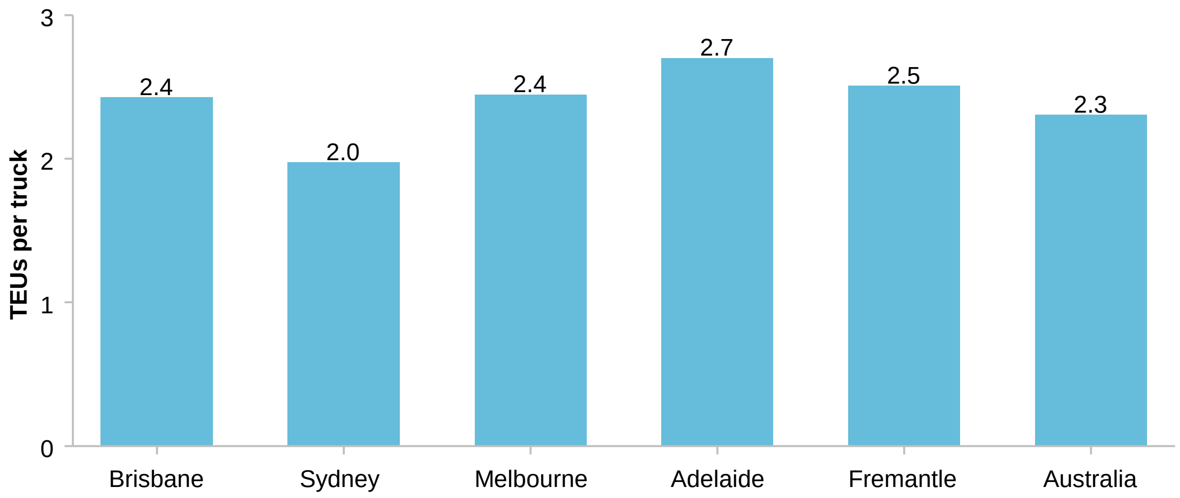
Backloading of trucks

Backloading refers to trucks which haul containers on both the inbound and outbound legs of a single trip to a port. Such operations make more effective use of trucks and landside infrastructure. *Waterline* calculates 'backloading' for the terminal, not the port precinct. That is, to be considered 'backloaded', a truck must unload and load at least one container at a single terminal. Therefore, backloading may be greater at port level, for example, a truck may unload a container at one terminal before loading at another. Empty containers dropped off at ECPs are also not counted towards backloading.

The share of backloaded trucks varied widely across Australian ports (figure 15). Adelaide had the highest share, and close to twice the rate of Melbourne which was the next best port. The higher degree of backloading in Adelaide corresponds with the higher truck utilisation rates in figure 14. That is, each truck transported more containers because 28 per cent of trucks both dropped off and picked up containers. Similarly, the lower backloading rates in Sydney shed light on why truck utilisation rates appear to be so low in Sydney.

Figure 14 – Sydney has the lowest rate of truck utilisation[a]

Average truck utilisation rate, 2019

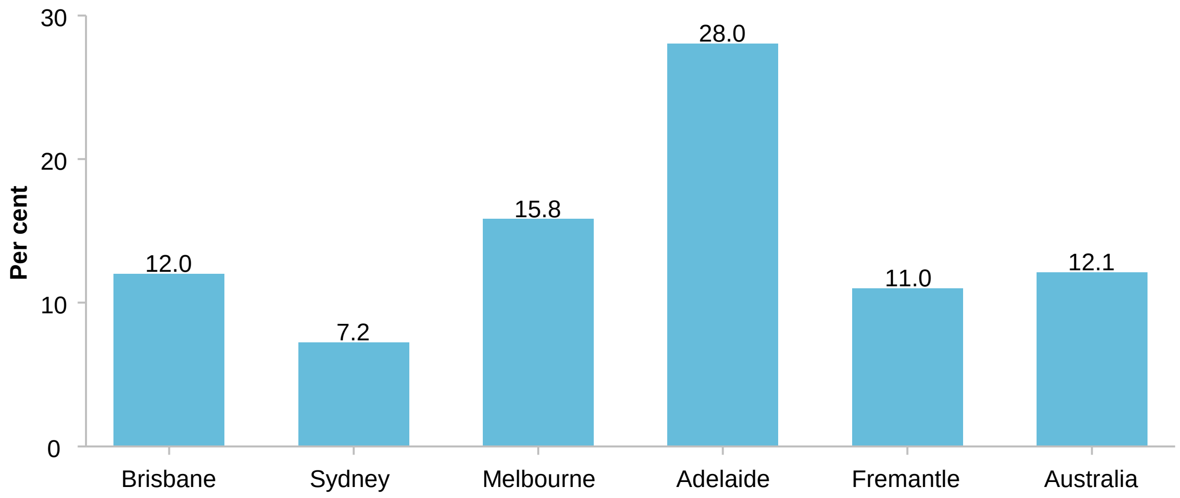


a. Average number of TEUs handled per truck. Calculated as the count of TEUs through the VBS/TAS systems divided by the total number of VBS/TAS trucks used.

Source: BITRE (2021).

Figure 15 – Sydney also had the lowest share of backloaded trucks

Per cent of trucks backloaded, 2019



Source: BITRE (2021).

7. The productivity of Australian container ports internationally

This section addresses the terms of reference directive to benchmark Australian ports internationally. An explanation of benchmarking is presented in box 5.

The existing benchmarking evidence suggests that Australian container ports lag behind international ports (see appendix C for a detailed review). As noted above, the World Bank (2021) found that most of Australia's container ports were ranked in the bottom 25 per cent of the 351 ports benchmarked, which suggested that Australia's ship turnaround times are slower than many other ports (see section 2). The ACCC (2021) recently noted that Australian ports lagged behind their New Zealand counterparts in terms of crane rates, elapsed labour rates and ship rates. Further, the ACCC noted that median time in port for container ships visiting Australia was 1.4 days in 2020 — 'more than four times as long as Japan, more than double compared to China and 67 per cent greater than time that ships spent in Singapore or New Zealand' (p. 62). Meanwhile, a recent academic study found that Australian container ports were ranked in the 2nd highest quartile for their size (from a sample of 213 ports), in a study of technical efficiency (Ghiara and Tei 2021). Taken as a whole, this evidence suggests that Australian ports could use their physical inputs more efficiently when compared to similar sized ports.

This section contributes to this literature in by:

- investigating *why* the Australian ports ranked poorly in the World Bank's CPPI study
- presenting an alternative approach to the World Bank for benchmarking Australian container ports internationally.

Ideally, the international benchmarking of port performance would take a holistic approach and capture performance on the marineside, quayside and landside. Due to the lack of data on landside metrics, however, the focus in the following analysis is only on the performance of the marineside and quayside. Future research may be able to take a more holistic approach if comparable international data on landside performance becomes available.

Box 5 – What is benchmarking?

Benchmarking is the process of comparing the performance of an individual organisation against a benchmark, or ideal, level of performance. Benchmarks can be set on the basis of performance over time or across a sample of similar organisations, or against some externally set standard.

The core reason for benchmarking is to identify performance gaps and areas of potential improvement. Benchmarking is also used to encompass the process of identifying 'best practices' — that is, finding ways of doing better.

Benchmarking primarily addresses technical efficiency, or how ports compare in terms of the volume of output produced given the inputs used in production. The best practice identified is not necessarily economically efficient — that is, the best possible use of resources from a community perspective.

Performance benchmarking can be undertaken to determine how well some parts of the Australian waterfront service industries compare in relation to their counterparts in other countries. In the Commissions *International Benchmarking of the Australian Waterfront* (1998) study, the main focus for

Box 5 – What is benchmarking?

performance comparisons were charges and service outcomes for importers and exporters; and selected indicators of labour and capital productivity.

A range of factors impact on the usefulness of benchmarking. The three main ones include:

- the accuracy and integrity of the data used in the analysis
- the difficulty in ensuring that comparisons are being made between like-with-like situations
- that lower observed performance may not equate with inefficiency. For example, it may be optimal to operate at 60–70 per cent of full capacity utilisation to prevent congestion in a port and retain spare capacity to cope with peaks in trade.

Source: PC (1998, pp. 1–3) and SCRCSSP (1997, p. 13).

Unpacking the World Bank's Container Port Performance Index

The World Bank, in conjunction with IHS Markit, developed the Container Port Performance Index (CPPI) to enable comparisons of quayside performance.

As noted above (table 1), the results suggested that Australia ports took longer than most international ports to turnaround ships.

The World Bank received criticism for not comparing like-for-like ports (section 2), but importantly their method compared port hours for a given ship and call size to improve comparability. For example, port hours for a ship sized between 5000 and 8500 TEU capacity and a call size between 2001 and 2500 containers are compared across ports. Performance in each of these ship-call size categories are aggregated to create a single performance measure for each port. (Appendix D provides more details of the methodology.) Regardless, there are a number of methodological and data-related issues that could affect the rankings of Australian ports in the CPPI (box 6).

The Commission obtained the data that underpinned the World Bank study (that is, IHS Markit's Port Performance Program data) to understand *why* Australian ports ranked so poorly in the CPPI.

Box 6 – Could aspects of the CPPI method affect the ranking of Australian ports?

A number of methodological choices and data issues may have affected the CPPI rankings of Australian ports, particularly in relation to the handling of larger ships. As two methodologies were used to construct the index, the approach the issue relates to is presented in parentheses.

- Small sample size issues. There are 43 unique ship call size categories. This means that performance will be based on a small sample of vessels for ports with few ship calls and the measures may, therefore, not be overly reliable. For example, Australia received under 230 visits from large ships in 2019-20 (8501-13 500 TEUs). (Both approaches.)

Box 6 – Could aspects of the CPPI method affect the ranking of Australian ports?

- Outliers in the data can inflate average port hours. For example, a port that had one ship at anchor for a few days could substantially increase average anchorage hours and, therefore, port hours, making the port seem inefficient. (Both approaches.)
- The imputation method for missing data might bias the performance of a port. Relative performance in call sizes for which there was sufficient data was used to approximate performance for call sizes with missing data. As such, good or bad performance can cascade across missing call sizes. For example, Brisbane's relatively good performance for the call size range 2001–2500 containers would also be attributed to larger call sizes (figure 18). (Both approaches.)
- For a given a ship size, global frequencies of call sizes are used as weights to construct the index. The Australian call size frequencies differ from the global frequencies, which might distort the scores for Australian ports because higher weights are placed on call sizes that are not as common in Australia. (Administrative approach.)

It is not possible to replicate the CPPI and, therefore, it is difficult to assess whether these issues cause material differences in the rankings.

However, the Commission can rule out a few aspects of the methodology that do not materially affect the rankings of Australian ports:

- the use of the fuel consumption index, which applies progressively higher weights to larger ships to aggregate ship level performance to a port score. The use of this index did not materially affect the rankings for Australian ports. That is, even if all ship sizes received equal weighting, the rankings of Australian ports remained relatively unchanged. This is not to say that ports that handled large ships well did not get a boost to their ranking from this weighting approach (both approaches)
- excluding some ports from the different ship size categories and attributing a score of zero to these ports essentially gave them the average score and, therefore, should not bias the rankings. For example, all Australian ports received a zero score for ships larger than 13 500 TEUs, since no Australian ports handle ships this large (both approaches.)

Why did Australian ports rank poorly?

Before diving into the results it is helpful to understand the types of ships calling at Australia's major container ports and call sizes, since the World Bank takes this information into account to increase the comparability of ports.

The global and Australian distribution of ship and call sizes is presented in figure 16. First, a clear difference is that Australian ports did not receive ships larger than 13 500 TEU capacity in 2019-20. In fact, Australia received under 230 calls from ships between 8501 and 13 500 TEU capacity. The majority of ships calling at Australian ports are between 1501 and 8500 TEU capacity. Second, for a given ship size, Australian ports receive a higher proportion of larger call sizes than the global average. Thus Australian ports typically service small to mid-sized ships, typically with larger call sizes than the global average.

Figure 16 – Ship and call size frequencies, 2019-20[a,b]

Each row presents the per cent of visits in each call size group

a) All ports

Ship size group (TEU)	Call size group (number of moves)									
	<250	251-500	501-1,000	1,001-1,500	1,501-2,000	2,001-2,500	2,501-3,000	3,001-4,000	4,001-6,000	>6000
<1,500	27.0%	39.6%	28.5%	4.9%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%
1,501-5,000	9.8%	24.8%	36.1%	17.1%	7.7%	2.7%	1.0%	0.7%	0.2%	0.0%
5,001-8,500	2.6%	9.7%	27.4%	23.2%	15.6%	9.5%	5.2%	4.5%	1.9%	0.3%
8,501-13,500	1.3%	6.7%	19.1%	18.2%	16.3%	11.9%	9.0%	10.0%	5.2%	2.1%
>13,500	0.2%	1.3%	5.5%	7.9%	10.5%	11.6%	11.2%	22.1%	22.4%	7.5%

b) Australian ports[c]

Ship size group (TEU)	Call size group (number of moves)									
	<250	251-500	501-1,000	1,001-1,500	1,501-2,000	2,001-2,500	2,501-3,000	3,001-4,000	4,001-6,000	Total
<1,500	23.1%	54.9%	19.8%	0.0%	2.2%	0.0%	0.0%	0.0%	0.0%	91
1,501-5,000	1.4%	12.2%	36.0%	29.2%	18.1%	2.9%	0.2%	0.0%	0.0%	1391
5,001-8,500	0.1%	1.5%	22.0%	22.0%	21.3%	18.7%	8.1%	6.2%	0.2%	1217
8,501-13,500	0.0%	1.3%	10.6%	25.2%	25.2%	15.0%	11.5%	11.1%	0.0%	226
Total	40	570	241	811	731	301	128	100	3	

a. Each row sums to 100%. **b.** The shading shows, for a given ship size group, which call size group is most frequent. Darker blue shades indicate a higher percentage, grey indicates a lower percentage, and white indicates no observations for a given row. **c.** The column for call sizes greater than 6000 containers and the row for ship sizes greater than 13 500 are excluded because Australia did not receive ships or call sizes in these groups.

Source: IHS Markit Port Performance Program and the World Bank (2021).

The appendix of the World Bank study pointed to issues in the relatively long time that it takes Australian ports to turn ships around (even after taking into account ship and call size) (table 8).[31] The performance of Australian ports — in terms of their percentile rank — deteriorated as ship sizes increased. While the Australian ports did not rank particularly well for the feeder and small ships, their performance was particularly poor for medium and large ships. The exceptions were Brisbane, which received a higher ranking than other Australian ports for large ships, thanks to them having generally faster turnaround times, and Sydney which handled even the feeder ships slowly.[32]

[31] Turnaround times used in the CPPI exclude steam-out time.

[32] As noted above, there appear to be some data issues for arrival times in Sydney and Adelaide.

Table 8 – The performance of Australian ports deteriorated as ship sizes increased[a,b]

CPPI percentile rank by ship size, 2019-20

	Feeder <1500 TEUs (219 ports)	Small 1501-5000 TEUs (331 ports)	Medium 5001-8500 TEUs (213 ports)	Large 8501-13 500 TEUs (162 ports)
Brisbane	64%	54%	73%	69%
Sydney	84%	71%	89%	91%
Melbourne	-	72%	75%	88%
Adelaide	-	73%	96%	93%
Fremantle	-	63%	80%	90%

a. Not all 351 ports are included in each ship size category because not every port handles each ship size. **b.** The percentile rankings for ship sizes greater than 13 500 twenty-foot equivalent (TEU) container capacity are excluded from the table since Australian ports were not visited by these ultra large ships.

Source: Adapted from the World Bank (2021).

And the data reveal how slow Australia's major container ports are at turning ships around relative to global averages (figure 17). Figure 17 presents data on turnaround times for different ship-size categories. These data were derived by aggregating turnaround times for different call sizes within each ship-size category. The potential influence of call size on turnaround times was taken into account by using global call size frequencies to weight data for all ports rather than port-specific frequencies.[33] The average turnaround time for medium and large ships was above the international average at all Australian ports and Sydney, Fremantle and Melbourne had slower turnaround for feeder and small ships. Given underperformance is relatively pronounced for medium and large ships, the following analysis focuses on these ship sizes.

Australian ports were substantially slower than the top three international ports at turning around *medium*-sized ships of all call sizes, and were typically slower than the average global port (figure 18). They also took up to three times longer to turn around *large* ships than the best international ports and longer (often considerably so) than the average international port (figure 19). Yokohama (Japan), Qingdao (China) and King Abdullah (Saudi Arabia) consistently had the fastest turnaround times for larger ships (box 7). Across the call sizes presented, Yokohama performed the best, with little change in port hours even as the call size increased.

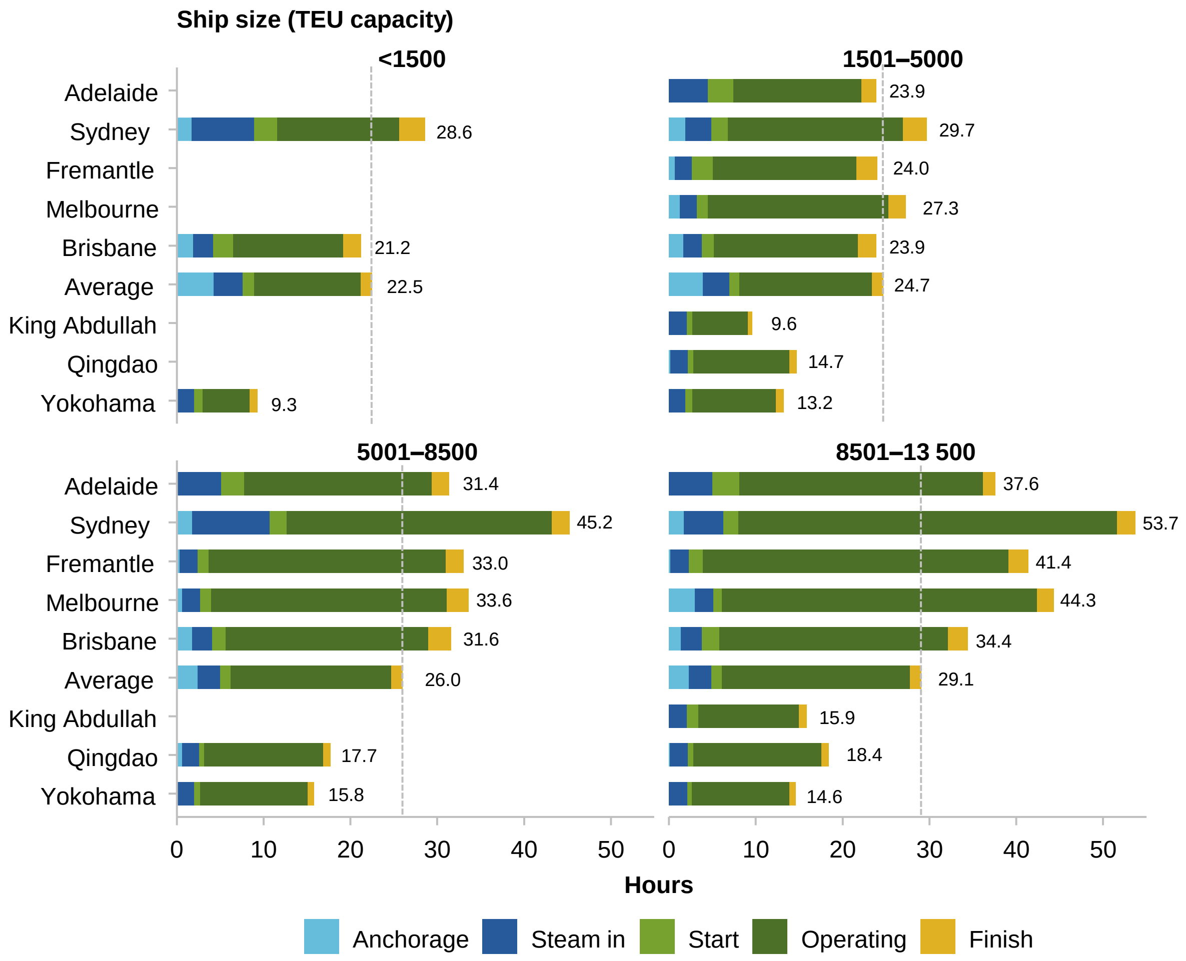
Arrival process

Slower arrival processes (that is, anchorage plus steam-in time), are one potential contributor to Australia's major container ports recording longer turnaround times for large ships. In 2019-20, most Australian ports had average arrival times that were in line with or faster than the average international port (figure 17). The outlier is Sydney, where arrival times were longer than the average international port and other Australian ports (as discussed above).

[33] The World Bank used a similar approach when constructing the CPPI.

Figure 17 – Turnaround times at Australian ports are above international averages[a,b,c,d]

Port hours by ship size and component, selected ports and global average, 2019-20

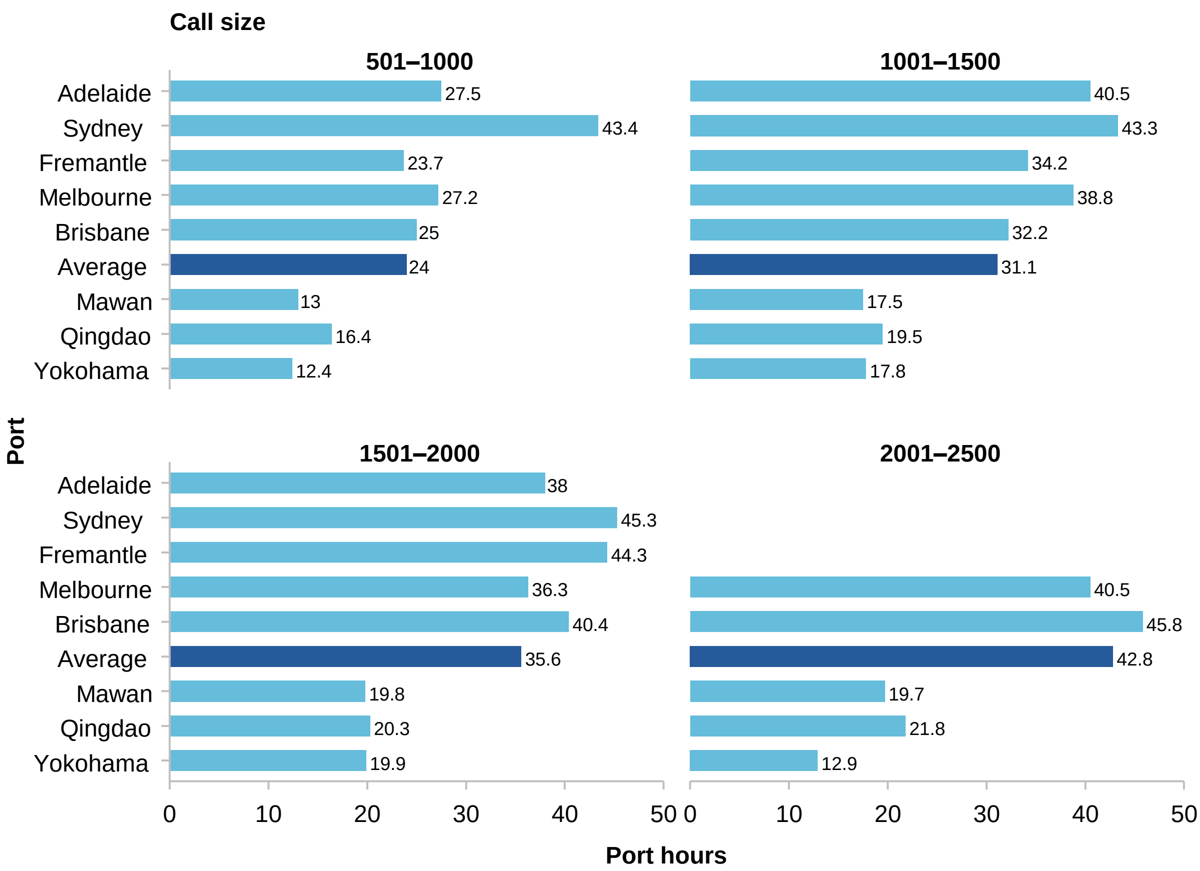


a. Port hours in the CPPI exclude steam out time. To aggregate the data to ship-size level, the influence of call size is neutralised. This is done by using global ship-call-size frequencies, rather than port-specific frequencies, to weight data and aggregate performance to ship-size level. **b.** Gaps in figure indicate that the port did not receive ten visits in the period. **c.** Top performers in the CPPI are included for comparison. **d.** Steam-in times for Sydney are likely overstated because they include time that should be attributed to anchorage. Conversely, anchorage times are likely understated. This issue is described in section 6.

Source: IHS Markit's Port Performance Program data.

Figure 18 – Australian ports take longer than international ports to turnaround *medium* sized ships for a given call size[a,b]

Average port hours by selected call sizes, medium ships (5001-8500 TEUs), 2019-20

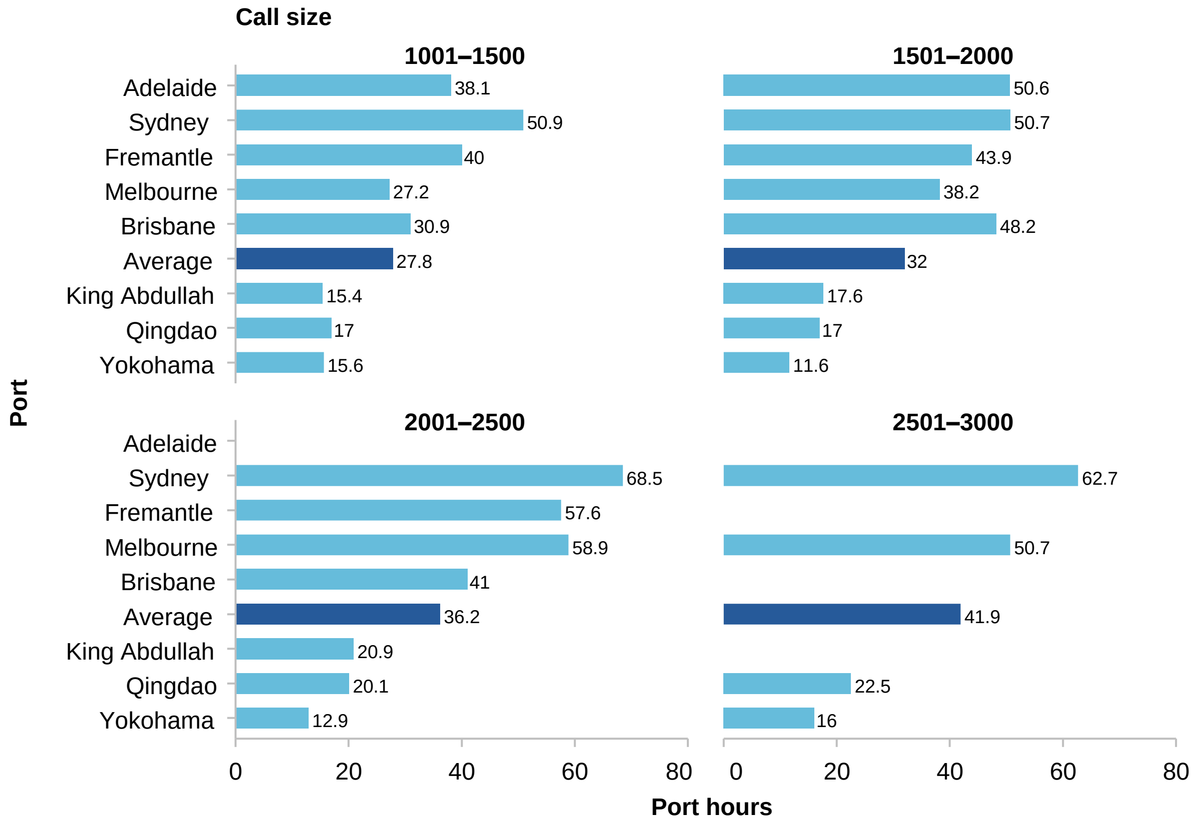


a. Gaps in figure indicate that the port did not receive ten visits in a six-month period. **b.** The three top international ports and the global average are presented for comparison.

Source: IHS Markit’s Port Performance Program data.

Figure 19 – Australian ports take longer than international ports to turnaround *large* ships for a given call size[a,b]

Average port hours by selected call sizes, large ships (8501-13 500 TEUs), 2019-20



a. Gaps in figure indicate that the port did not receive ten visits in a six-month period. **b.** The three top international ports and the global average are presented for comparison.

Source: IHS Markit's Port Performance Program data.

Box 7 – Top ranked ports are new and built to accommodate larger ships

The World Bank study does not discuss why ports rank the way they do. The Commission investigated the top performing ports of Yokohama, King Abdullah and Qingdao to identify characteristics that could contribute to fast turnaround times or efficiency more generally. The following is not an exhaustive list.

All three are relatively new ports or have new terminals within an older port. For example, King Abdullah port first opened and serviced a ship in 2013, while Qingdao's newest terminal opened in 2017. Because these ports are new, they were built and designed to accommodate growth in ship sizes and containerised trade and can therefore accommodate the largest ships (some up to 24 000 TEU capacity).

To achieve their goals, these ports have:

- strategic locations at the entrances of deep water bays or harbours (sometimes man made) which helps to reduce steam-in times and minimise weather disruptions

Box 7 – Top ranked ports are new and built to accommodate larger ships

- numerous long and deep berths, high numbers of large quay cranes (some with an outreach of 25 TEUs or twin lift capabilities) and large container yards. They also have room to expand by adding additional terminals or extending yards. This gives ports the ability to intensely work a ship which helps to reduce operating times
- good connections to the landside (all with direct access to highways, Qingdao with rail to dock) which may help to reduce container dwell times and truck turnaround times (but not necessarily ship turnaround times).

There are also port specific characteristics that could affect current and future performance.

Yokohama

- Unionised industrial action might happen once a year. When it does all Japanese ports are affected. Typically, it is scheduled for 24 hours on a Sunday in order to minimise disruption to operations (APM Terminals Yokohama, pers. comm., 23 June 2022).
- At the APM Terminal:
  - they handle more containers per berth hour than any other terminal (APM Terminals 2015)
  - some stevedoring companies (who handle the containers at this terminal) are owned by the shipping lines, helping to align the incentives to turn ships around fast (APM Terminals Yokohama, pers. comm., 23 June 2022)
  - an online vehicle booking system (CONPAS) has been introduced but so far there has been limited take up. The paper based (fax) system remains preferred (APM Terminals Yokohama, pers. comm., 23 June 2022).

King Abdullah

- Constructed on a greenfield site, the port therefore does not face many of the constraints present at historical ports (such as urban encroachment). There are also plans to expand the port to handle 20 million TEUs per year, through construction of additional terminals and a dedicated rail terminal adjacent to the port (King Abdullah Port 2022b).
- Investments in port technology include a Port Community System (a single online platform for document sharing that increases supply chain visibility) and Smart Gate System (which automates security functions, authenticating the identity of the driver, vehicle and cargo, which improves truck turnaround times) (King Abdullah Port 2022a).

Qingdao

- This is a fully automated terminal, which claimed to have reduce labour costs by 70 per cent and increase efficiency by 30 per cent compared with traditional terminals (CRI Online 2018).

Sources: APM Terminals (2022a, 2022b); IHS Markit’s Port Characteristics data; King Abdullah Port (2022a, 2022b, 2022c); Yokohama Port Corporation (2022).

Cargo operating times

Australian ports had longer cargo operating times than the international average and top performing ports for a given call size for both medium and large sized ships (figure 20). For example, for large ships and for a call size of 2001–2500 containers, cargo handling at Sydney and Fremantle took over 44 hours, Melbourne and Brisbane performed slightly better (above 36 hours), but Yokohama, Qingdao and King Abdullah took under 20 hours and the global average was 29 hours.

Two factors help to unpack why Australian ports had longer operating times for a given ship and call size:

- the average number of cranes deployed (crane intensity)
- the productivity of those cranes (gross crane rates).

For a given ship and call size, Australian ports used fewer cranes to service ships than the average international port and the top performing ports (figure 21). For example, Melbourne deployed about 3 cranes — the most cranes out of the Australian ports — to service large ships with a call size of 2001–2500, while Qingdao deployed about 5.6 cranes and Yokohama deployed 4.8 cranes. The international average was 3.8 cranes.

The productivity of the Australian cranes was similar to the international average (figure 22). Top ranked Yokohama had the highest gross crane rates, likely aided by some of their twin lift cranes (that is, a crane that can handle two forty-foot containers at once).[34]

The use of fewer cranes in Australian ports meant that it took longer to load and unload containers for a given ship call. This contributed to longer turnaround times and therefore poorer rankings of Australian ports.

The World Bank did not provide an analyses of how ports could improve their performance. Because the index is based on port hours (or turnaround times) anything that reduces this time would improve a port's ranking. The Commissions analysis suggests that Australian ports could improve their ranking by reducing the proportion of ships anchoring and the waiting time when anchored (to the extent that anchorage is caused by factors within the port or terminal's control). Australian ports could also work towards deploying more cranes (where feasible) to load and unload ships, especially for the larger call sizes.[35] These issues seem particularly prevalent for medium and large sized ships. Given ships are getting larger, Australian ports could focus efforts on handling these ships more efficiently, which would also improve their ranking in the CPPI.

That said, Australian ports should be aiming for improved efficiency, which depends on not just the level of outputs produced by ports (such as ship turnaround times) but also the efficient deployment of inputs (such as cranes) to achieve those outputs. The CPPI is only a partial measure of performance and, by itself, cannot be used to evaluate the efficiency of Australian ports. For example, even if deploying more cranes would lower turnaround times, this is only efficient if the cost of the additional cranes is more than offset by the benefits of the reduced turnaround times. The CPPI ranking does not evaluate such a trade-off.

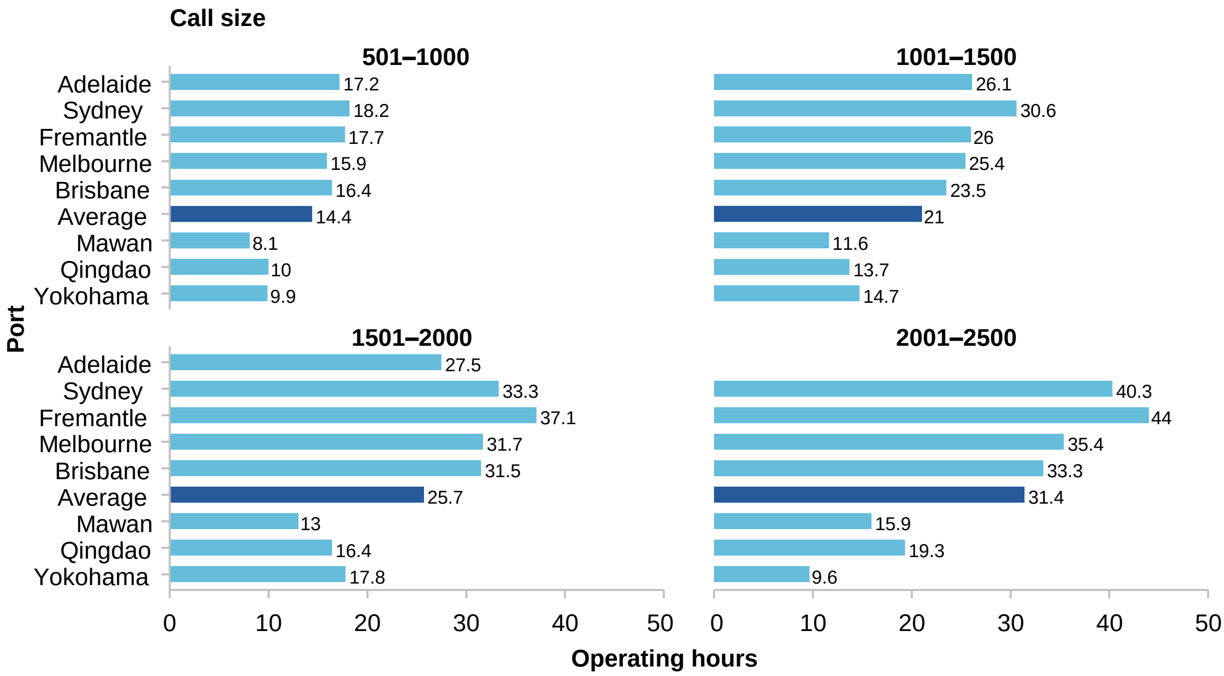
[34] Shipping Australia (sub. DR132, p. 3) commented that average international crane rates are poor and that Australian ports have 'significant capacity to boost crane rates to match best-in-class performance'.

[35] DP World (sub. DR140, p. 15) submitted that part of the reason Australian ports use fewer cranes is because of the older terminal infrastructure which restricts the load and distance between quay cranes when operating. However, the Commission has seen no evidence to support the contention that quay infrastructure is unable to accommodate additional cranes at the margin at major Australian container ports.

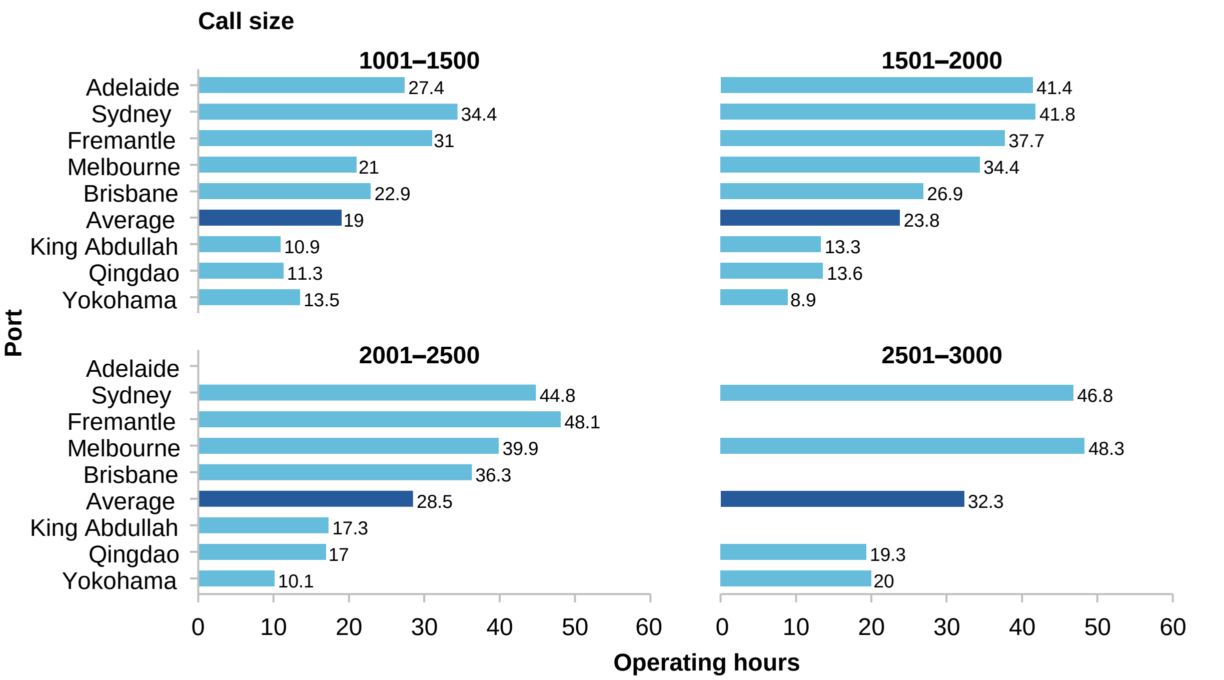
Figure 20 – Operating times are above the international average[a,b]

Average operating hours by selected call sizes, 2019-20

a) Medium ships



b) Large ships



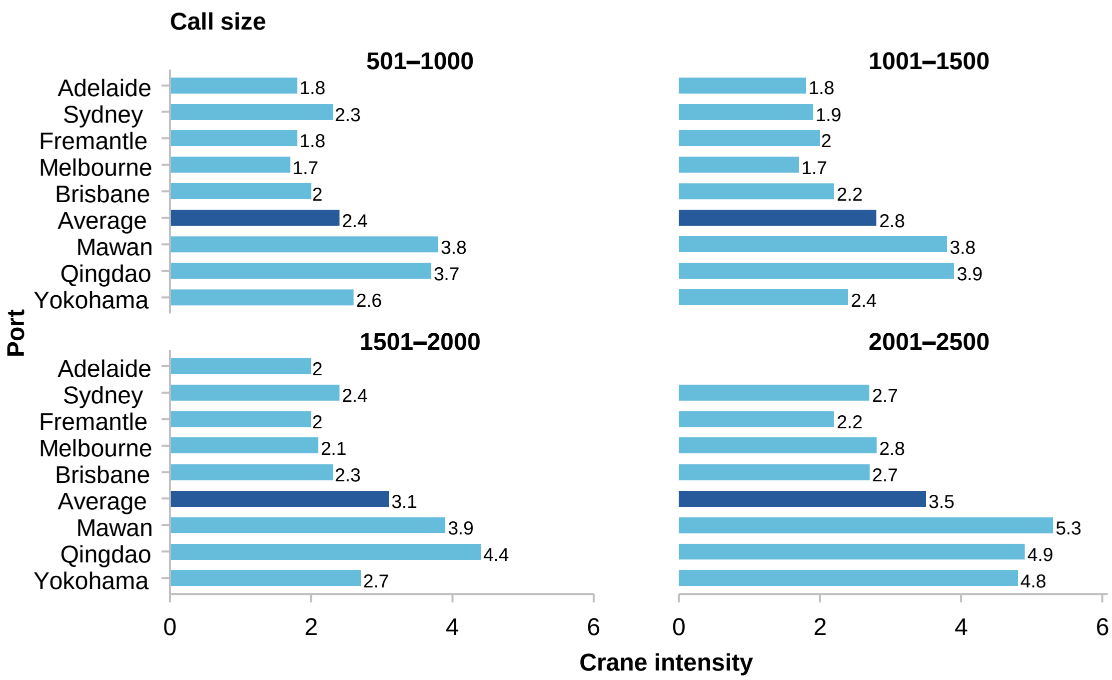
a. Gaps in figure indicate that the port did not receive ten visits in a six-month period. **b.** The three top international ports and the global average are presented for comparison.

Source: IHS Markit's Port Performance Program data.

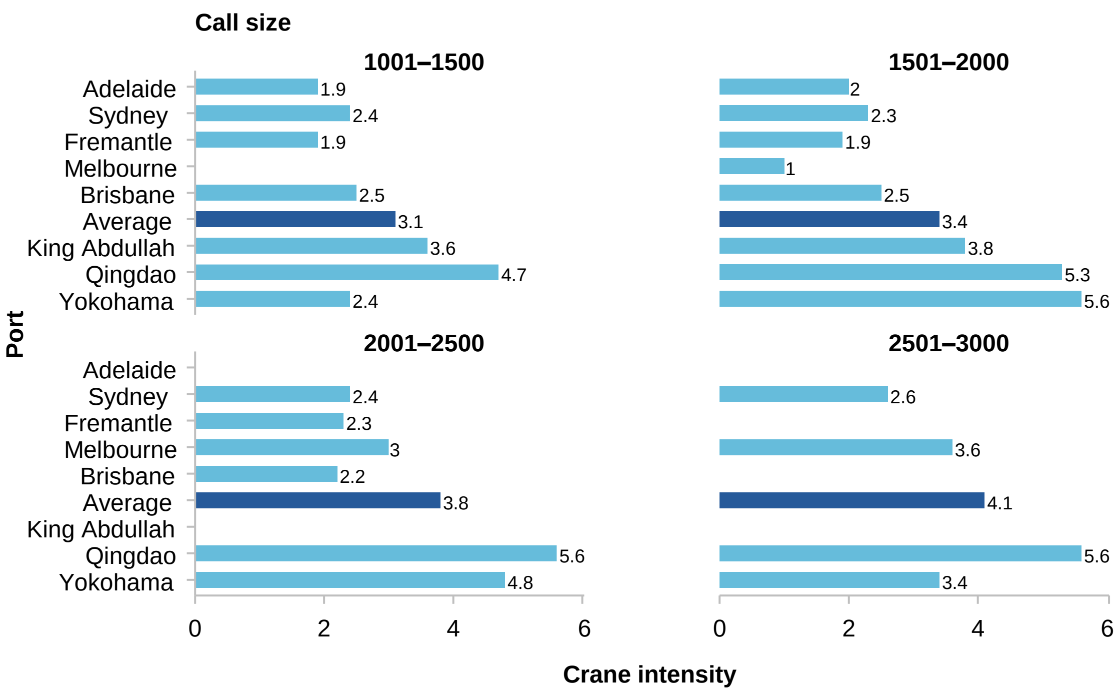
Figure 21 – Australian ports used fewer cranes[a,b,c]

Average number of cranes used by selected call sizes, 2019-20

a) Medium ships



b) Large ships



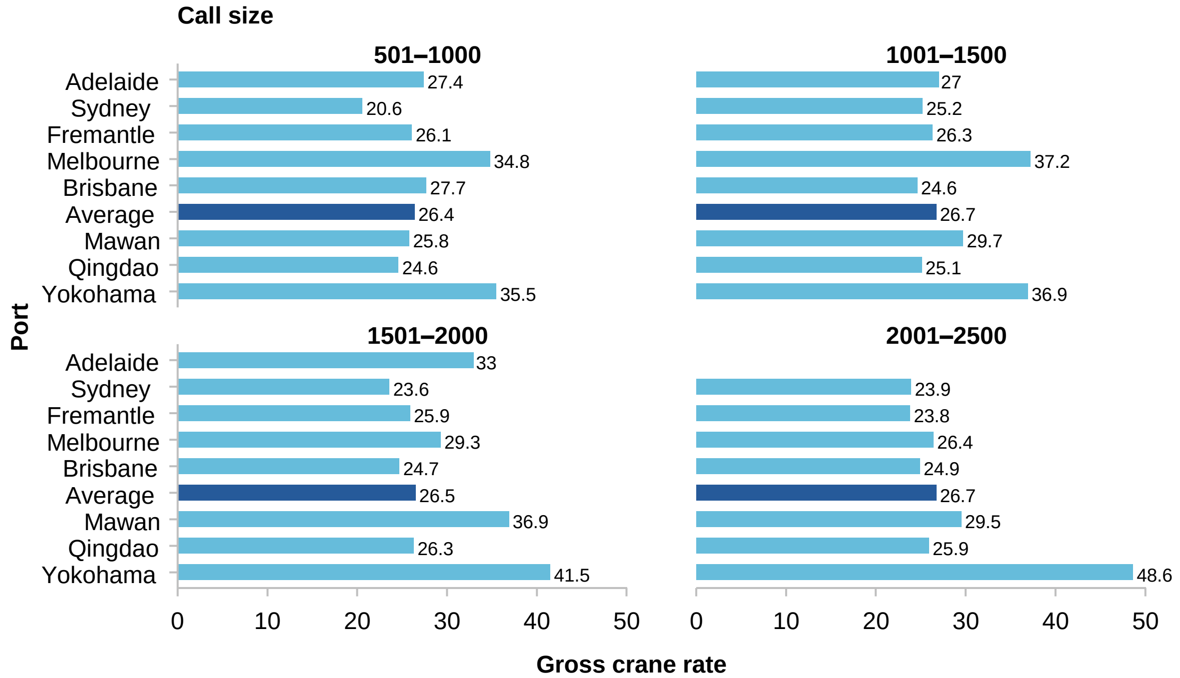
a. The average number of cranes (or crane intensity) is calculated as gross crane hours divided by operating hours. **b.** Gaps in figure indicate that the port did not receive ten visits in a six-month period. **c.** The three top international ports and the global average are presented for comparison.

Source: IHS Markit's Port Performance Program data.

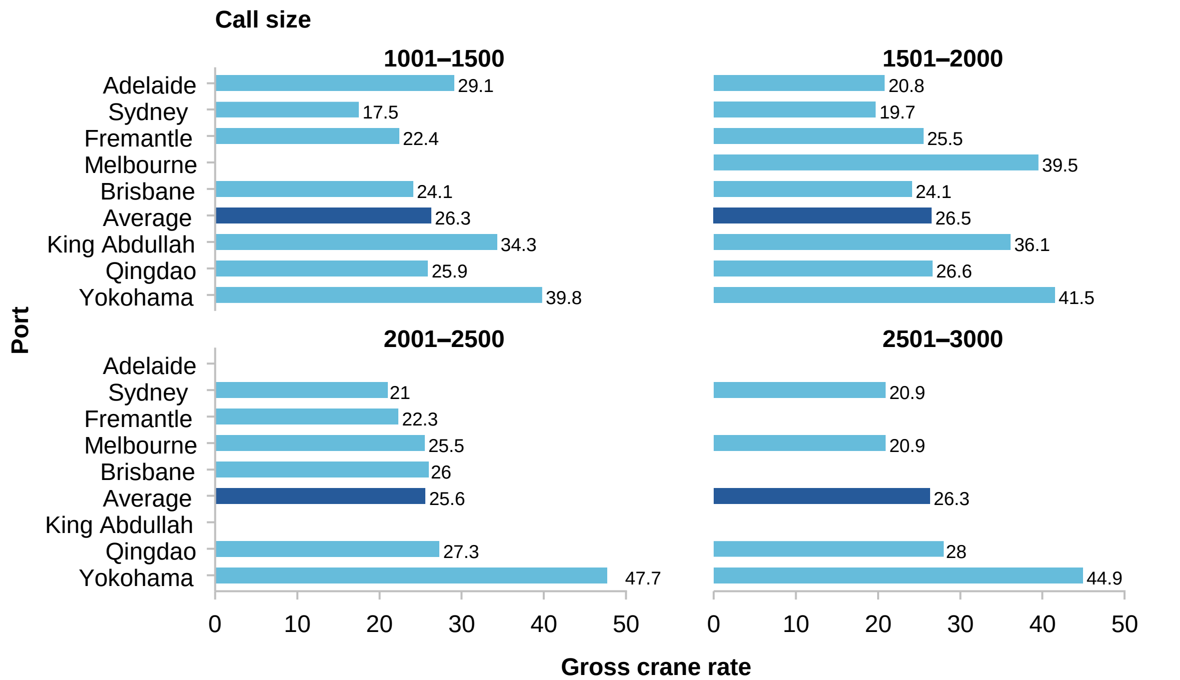
Figure 22 – Gross crane rates are similar to an average international port[a,b]

Average gross crane rate by selected call sizes, 2019-20

a) Medium ships



b) Large ships



a. Gaps in figure indicate that the port did not receive ten visits in a six-month period. **b.** The three top international ports and the global average are presented for comparison.

Source: IHS Markit's Port Performance Program data.

An alternative way to benchmark container ports

The World Bank study is closely related to the benchmarking framework described in section 5, in that it focuses on time-based metrics (the turnaround times of ships). Given the newness of the Port Performance Program data and criticisms of the CPPI, the Commission sought to use a more conventional approach to benchmark the technical efficiency of international container ports — estimating a production possibility frontier using data envelopment analysis (DEA, box 8) and assessing where Australia's ports sit relative to that frontier.

Port characteristics data

A key challenge for an international benchmarking exercise is obtaining data that are accurate and comparable across ports. As noted by the World Bank there is a:

> … lack of a reliable, consistent, and comparable basis on which to compare operational performance across different ports. While modern ports collect data for performance purposes, the quality, consistency, and availability of data, the definitions employed, and the capacity and willingness of the organizations to collect and transmit data to a collating body, have all precluded the development of a comparable measure (or measures) to assess performance across ports, and time. (World Bank 2021, p. 8)

Typically, data used for benchmarking ports using a production possibility frontier approach are collected manually for a sample of ports in specific regions or countries (appendix C). Data are usually collected from port authorities, terminal operators, industry reports, or the Containerization International Yearbooks (now discontinued) for a sample of ports. As a result, sample sizes are typically small, ranging from 5 to 70 ports.

For the DEA, the Commission has drawn on IHS Markit data on port, terminal and berth characteristics that cover almost 1500 ports that receive containers (appendix A). The data contain details of port inputs and outputs which are crucial for the DEA. For example, information about the number of cranes, berth lengths and throughput are collected. The data allow the Commission to benchmark a large sample of ports compared with the existing literature.

However, these data are not without issues. Investigations into the data suggested that there are some inconsistencies with data found on port authority websites. For example, for some ports the data understated the number of berths. To improve accuracy, the data for a significant number of ports have been cross-checked with port authority websites and other online sources. However, not all port data has been verified. Further verification of the data would allow for more robust analysis.

Box 8 – What is Data Envelopment Analysis (DEA)?

Data Envelopment Analysis (DEA) is an analytical tool that can assist in the identification of technical efficiency among a group of firms. Such identification can highlight the potential for efficiency improvements.

DEA is a linear programming technique (non-parametric) used to estimate the production function of ports (figure below). The DEA estimates the maximum potential output for a given set of inputs assuming either constant (CRS), variable (VRS) or non-increasing returns to scale (NIRS). The model identifies the apparent best ports as those on the frontier (points A, C and E for the VRS frontier depicted in the figure below) — these ports receive a technical efficiency score of one. Ports that operate within the frontier (point B and D for the VRS model represented in the figure below) receive a technical efficiency score of less than one, which is determined by their performance relative to that of the best performers

Box 8 – What is Data Envelopment Analysis (DEA)?

(calculated as B_0B_2/B_0B). The input orientated model implies that these ports could reduce the level of inputs and achieve the same level of output.

Estimating a DEA requires data on inputs and outputs for a sample of ports. These should reflect the actual objectives and process of container port production as accurately as possible.

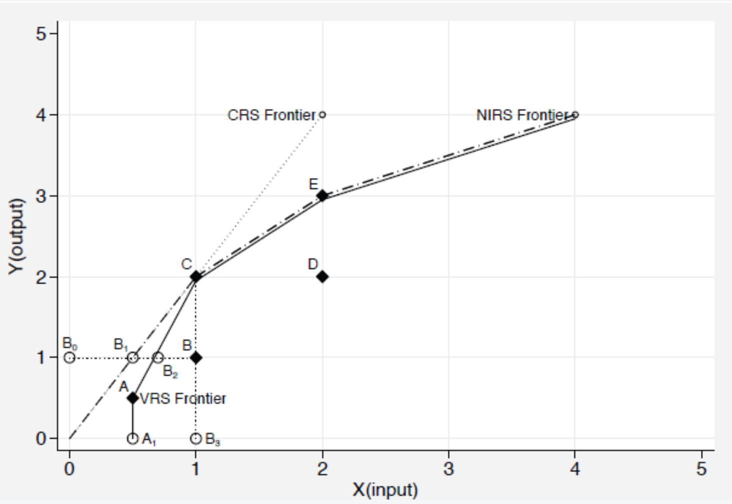
The main advantages of DEA are the ability to:

- incorporate multiple inputs and outputs and that price data are not required (only quantity data)
- identify the 'peers' for inefficient ports such that the peers provide a set of potential role models that a port can look to for ways of improving its efficiency.

The main disadvantages are that:

- the model is sensitive to data measurement error, data outliers, input and output variable specification and sample size. This means that inefficiency can be confused with poor model specification
- it assumes that only those inputs specified in the model are used to produce the output.

An example of a production function estimated using DEA



Source: Ji and Lee (2010) and SCRCSSP (1997).

Identifying comparable ports

The value in benchmarking arises from comparing like-for-like ports. That is, comparing Australian ports to ports overseas (or other Australian ports) that possess comparable characteristics allows for an assessment of what improvements may be possible and the extent to which they are possible. For example, Australian ports may never be able to achieve the same levels of efficiency as transhipment ports such as Shanghai, Singapore or Busan, which handle large volumes of containers from very large ships and move significant numbers of containers from ship-to-ship. Nor might Australia achieve the economies of scale present at larger ports (for example, the throughput of the port of Shanghai is five times larger than all Australian ports combined).

But identifying similar ports is a challenging exercise (box 9). There are many factors that make Australian ports different to each other (such as the level of throughput, frequency of ship visits, port infrastructure and operations and restrictions on vessel height and size) and different in an international context. DP World Australia (sub. 49, p. 36) noted that Australian container ports are ‘different in many ways to their overseas counterparts’, for example they:

- are small by international standards (because each port serves one major city rather than multiple)
- operate as a small-volume destination at the end of a long global trade route
- are predominantly an importer of containerised goods
- major demand centres are located on the coast, and mostly co-located with the international container ports, therefore ports are located on constrained land.

The Maritime Union of Australia (sub. 59) noted further differences in terms of labour and human rights standards (p. 71) and Australia’s ‘notoriously challenging yard layouts which also impacts on yard logistics’ (p. 31).

Finding data for and accounting for these characteristics in any modelling exercise is difficult, therefore few studies try to identify comparable ports. Most instead compare ports within a country or a region or group ports with similar throughput levels. In previous work, the Commission relied on the advice of consultants to select benchmarking ports (PC 1998, 2003). These ports had direct liner services to Australia, such as Singapore, Los Angeles, Hamburg and Auckland. Some of these no longer seem like good benchmarking partners. For example, Singapore is predominantly a transhipment port, while Los Angeles is at least 3 times bigger than the largest Australian port.

For the DEA, the Commission selected ‘broadly comparable’ ports by selecting origin-destination ports (rather than transhipment ports) and ports with similar throughput levels to the five major Australian container ports. (The throughput of Australian ports ranges between 0.4 and 3 million TEUs annually).

Specifically, the Commission initially selected all 351 port ports included in the World Bank study. From these:

- 30 ports were excluded as they had a transhipment incidence higher than 50 per cent. That is, the share of the total port throughput that is ‘ship to ship’ is greater than or equal to 50 per cent as this suggests these ports are high to pure transhipment ports (Notteboom, Pallis and Rodrigue 2022). These ports tend to be located along the main circum-equatorial maritime route through the Panama and Suez Canal and the Straits of Malacca and Gibraltar and provide connectivity between north-south and east-west shipping lanes. Examples include Singapore, Port Said, Jebel Ali, Columbo, Rotterdam and Hong Kong
- 17 ports were excluded as their throughput was larger than 7 million TEUs and 107 ports were excluded as their throughput was smaller than 0.25 million TEUs. While the DEA method accounts for differences in throughput, the throughput levels of the ports differ markedly and removing the ‘tails’ improves the DEA modelling by removing outliers (figure 23). Similar restrictions have been performed in the literature (Ghiara and Tei 2021)
- 31 ports were excluded because of missing data on key variables (described below).

Box 9 – Finding comparable ports is important but challenging

Identifying comparable ports is a challenging task but it is important for benchmarking.

> While the achievement of best international practice must be sought within a port, there is, however, a danger of making unfair international comparisons if there is no similarity between contexts. It is necessary to place the efficiency of a port in perspective with ports of similar characteristics with regard to trade volume, infrastructure and port operations. (Tongzon 1995, p. 171)

Box 9 – Finding comparable ports is important but challenging

Many submissions to the inquiry also noted the importance of comparing like-for-like ports, but few suggested methodologies to do so.

Shipping Australia Limited (sub. 11, pp. 103–106) provided a method for and identified comparable ports:

- start with the top 100 ports by throughput (Lloyd's List) and including NZ ports
- select ports in nations that were most comparable to Australia using the socio-cultural characteristics in the index created by Hofstede Insights (these were Canada, NZ, South Africa, the UK and US)
- add a selection of ports that had a similar throughput to Fremantle and Adelaide (because these were much smaller than ports in the top 100 list). This included Halifax, Lyttelton, Auckland and Tauranga
- ensure that selected ports had comparable functions (that is, select destination ports rather than origin and transhipment ports)
- review satellite imagery to determine if ports have similar physical characteristics.

Their method resulted in 15 international ports being identified as highly comparable to Australian ports. The ports in this small sample are still different. For example, some are restricted by bridges and others are not (p. 105).

The Maritime Union of Australia (sub. 59, p. 85) suggested at a minimum that, the comparable ports:

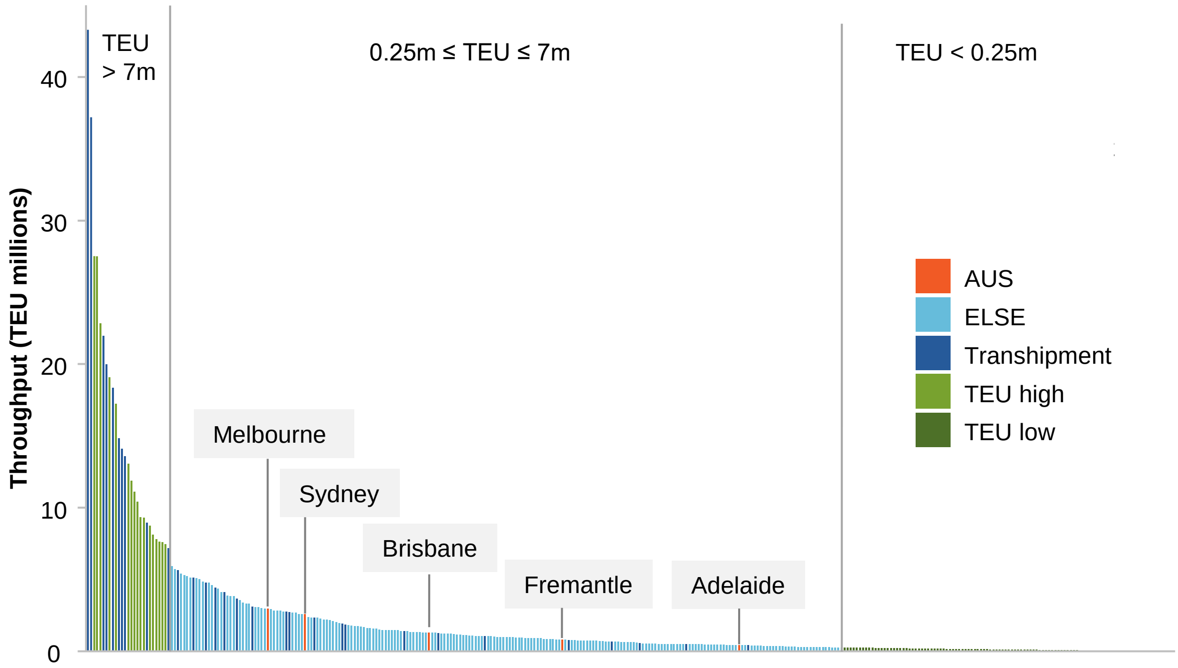
- are origin-destination (or gateway) ports and not predominantly transhipment or hub ports
- handle a similar number of containers/TEUs annually
- handles a similar full to empty ratio and 20-foot to 40-foot ratio
- yard area and configurations are similar
- the ship size ranges (TEU, load on arrival and beam) serviced by the port are similar
- have a similar level of terminal operators.

The Commission sought to take on board this advice, however, finding data for and accounting for all these characteristics to identify comparable ports is difficult in practice.

This process goes some way to identifying ports that are more comparable to Australian ports in terms of their predominant activity (transhipment verse origin-destination) and size (level of throughput) (figure 23). Overall, 166 ports are identified as broadly comparable. including ports in North America (for example, Montreal, Vancouver, Halifax, Charleston, Houston), South America (Callao, San Antonio, Santos), New Zealand (Tauranga, Auckland), Europe (Felixstowe, London, Valencia, La Spezia, Le Havre), Asia (Shantou, Yokohama, Tokyo) and Africa (Durban, Lomé). The list includes those ports identified by Shipping Australia as highly comparable (box 9).

Figure 23 – Identifying comparable ports

Throughput of the ports used in the CPPI, 2019



Source: IHS Markit's Port Characteristics data.

The ports in the sample that are most similar in *size* to the Australian ports are presented in table 9.

Table 9 – Sample ports closest in size to Australian ports

	First	Second	Third	Fourth
Brisbane	Yarimca (Turkey)	Da Chan Bay Terminal One (China)	Mawan (China)	Hamad (Qatar)
Sydney	Oakland (US)	Southampton (US)	Yokohama (Japan)	Yeosu (South Korea)
Melbourne	Houston (US)	Virginia (US)	Qinzhou (China)	Nagoya (Japan)
Adelaide	Lyttelton (NZ)	Itapoa (Brazil)	Tin Can Island (Nigeria)	Salerno (Italy)
Fremantle	Trieste (Italy)	Aqaba (Jordan)	Dublin (Ireland)	Algiers (Algeria)

Source: IHS Markit's Port Characteristics data.

Data envelopment analysis

As noted in box 8, the input and output variables used in the DEA should reflect the actual objectives and process of container port production as accurately as possible. The selection used here largely follows the precedent set by the literature (appendix C).

For the output variable:

> … container throughput is unquestionably the most important and widely accepted indicator of container port or terminal output. Almost all previous studies treat it as an output variable, because it closely relates to the need for cargo-related facilities and services and is the primary basis upon which container ports are compared, especially in assessing their relative size, investment magnitude or activity levels. Most importantly, it also forms the basis for the revenue generation of a container port or terminal. Another final, but extremely pragmatic, consideration is that container throughput is the most appropriate and analytically tractable indicator of the effectiveness of the production of a port. (Wang and Cullinane 2015, pp. 259–260)

As such, container throughput (TEUs) for 2019 is the output variable in the model.

Container port production depends crucially on the efficient use of labour, land and capital. Input variables should reflect each of these dimensions.

While labour is a critical input, it is rarely included in port studies because data are unavailable. Operations managers, crane operators and work gangs are just some examples of the types of labour that are critical to port production. Few studies include a labour input and when they do it is usually a poor proxy. For example, the number of port authority employees has previously been used as a proxy but this misses other types of labour that are necessary for port production and may simply introduce bias into models. While excluding labour is a major limitation of the Commission’s model it is criticism of the wider literature on port performance.

Land inputs are typically included in port studies, however, data are unavailable for the Commission’s analysis. Yard size can dictate capacity and flexibility to manage container traffic flows and store containers. While the IHS Markit Ports Characteristics data appeared promising for container yard area, the data were patchy and did not cover all terminals within ports, therefore aggregating terminal-level to port-level data would result in a misleading land input that could bias the model. Not including a land input is another limitation of the study.

Apart from labour and land inputs, other important inputs may be missing from the DEA model including:

> … berth occupancy, berth accessibility, proximity to major trade lanes, terminal/port connectivity (as proxied by the number and frequency of liner services that service the terminal or port), crane operating hours, different handling speeds of yard and quay cranes, equipment age and maintenance, the total capital invested in a terminal and associated equipment, average container interchange per ship and quayside water depth. However, the practical problem of obtaining data on each of these variables across the whole sample is likely to prove virtually insurmountable. (Wang and Cullinane 2015, p. 260)

Given data constraints, the model mainly includes capital inputs, including:

- number of terminals — a proxy for terminal-level competition within the port
- number of berths — a proxy for the number of ships a port can service
- total length of berths — a proxy for the size of ships a port can handle
- maximum draft — a proxy for the weight and depth of ships that a port can service
- the number of container cranes (separated into quay, mobile and other cranes to allow for technology differences across ports) — a key resource for handling containers and increasing container throughput.

A key implication of the set of variables included in the analysis is that the DEA only provides guidance on potential to improve technical efficiency in the long term. Many of these variables (such as the number of terminal operators and berths, and berth length) are effectively fixed in the short to medium term. Other factors that affect productivity are also ostensibly outside the control of port and terminal operators (such as the number of ship visits, their arrival times and the number of containers to be handled). And, aside from crane usage, there is minimal data on the inputs over which terminal operators have day-to-day control (such as employment and labour utilisation) that could influence their productivity.

Table 10 presents descriptive statistics for the 166 ports included in the DEA model. On average a port handles 1.5 million TEUs per year, using an average of two terminals, seven berths with a total length of two kilometres, 1.5 gantry cranes and 13.8 mobile cranes. The average maximum draft of visiting ships is 14.5 meters. There is significant variation in each of the variables. For example, ports in the sample used an average of 1.5 gantry cranes, but this ranged between 0 and 34 across the included ports.

There is variation in the size of the ports too. Throughput ranges between 0.3 and 5.7 million TEUs per year. The DEA model can account for different sizes of ports if a variable returns to scale production function (which is less restrictive than constant returns to scale) is estimated. This allows the best practice level of outputs to inputs to vary with the size of the ports in the sample. Results from a constant returns to scale model are presented for comparative purposes.

DEA can be applied in an input-oriented and an output-oriented way. An input-oriented model measures the potential proportionate reduction in input quantity that could be achieved without changing the output quantity. An output-oriented DEA measures the potential proportionate expansion in output quantity for a given input quantity. The Commission follows the literature in applying an input-orientated model. This model is well-suited to the port performance context because a port's output is not controlled by the port or terminal operators: the number of containers that pass through a port reflects the demand for imports by the local community and world demand for local exports. As such, port throughput is a 'derived' demand.

Table 10 – Sample descriptive statistics, 2019

Variable	Mean	Standard deviation	Minimum	Maximum
Throughput (million TEUs)	1.5	1.3	0.3	5.7
Number of terminals	2.1	1.2	1	6
Number of berths	7.2	5.0	1	26
Berth length (km)	2.0	1.3	0.3	5.7
Maximum draft (m)	14.5	3.3	8.2	30.0
Number of gantry cranes	1.5	4.0	0	34
Number of mobile cranes	13.8	11.3	0	41
Number of other cranes[a]	0.4	1.6	0	11

a. These are other types of quay cranes that are not mobile or gantry cranes.

Source: IHS Markit's Port Characteristics data.

Results

The DEA results point to most Australian ports having scope to improve the efficiency of their operations (table 11). If constant returns to scale are assumed, Melbourne is the most technically efficient of the Australian ports. Although when the more realistic and preferred variable returns to scale model is used, Adelaide is estimated to be fully technical efficient. Melbourne is found to have a score of 0.9 which is 10 per cent from the frontier and just above the average technical efficiency score for the sample of 0.89. Sydney, Brisbane and Fremantle have scores between 0.71 and 0.75 which are between 21 and 25 per cent from the frontier — well below the sample average. Technical efficiency scores for all ports can be found in appendix B.

The results suggests that most Australian ports are not technically efficient. This implies that most ports could reduce their physical inputs to achieve the same level of output.[36] An alternative, and more realistic, interpretation is that most Australian ports should be able to cope with an increase in throughput by using their inputs more efficiently (figure 24 — the vertical distance between the port and the frontier). But this interpretation depends on the ability of port operations and the landside to cope with increased container traffic (more ships or larger call sizes). Inefficiencies in port operations and on the landside could restrict quayside productivity — an interlinkage of the system that is not taken into account with the DEA. Note that figure 24 depicts a two-dimensional production function and because of this it depicts Adelaide within the frontier even though Adelaide is technically efficient.

Table 11 – Most Australian ports have scope for improvement[a,b]

Technical efficiency scores for Australian ports

Port	CRS model	VRS model	VRS Rank (percentile)	VRS Peers
Adelaide	0.62	1.00	1 (0.01)	Batangas, Douala, Posorja
Melbourne	0.87	0.90	101 (0.61)	Davao, Puerto Cortes, Chiwan, Qinzhou, Cat Lai
Sydney	0.69	0.75	125 (0.75)	Douala, Qinzhou, Cat Lai
Fremantle	0.56	0.73	128 (0.77)	Douala, Puerto Cortes, Chiwan, Taipei, Posorja
Brisbane	0.53	0.71	135 (0.81)	Douala, Qinzhou, Cat Lai

a. A variable returns to scale model was used to account for differences in throughput levels and economies of scale.
b. There were 87 ports out of the 166 ports in the sample that received a technical efficiency score of one in the VRS model, indicating the port was fully efficient. So, even though Melbourne has quite a high technical efficiency score, their percentile rank is in the bottom 60 per cent.

Source: Commission estimates using IHS Markit’s Port Characteristics data.

How can Australian ports improve their technical efficiency? The model provides two suggestions:

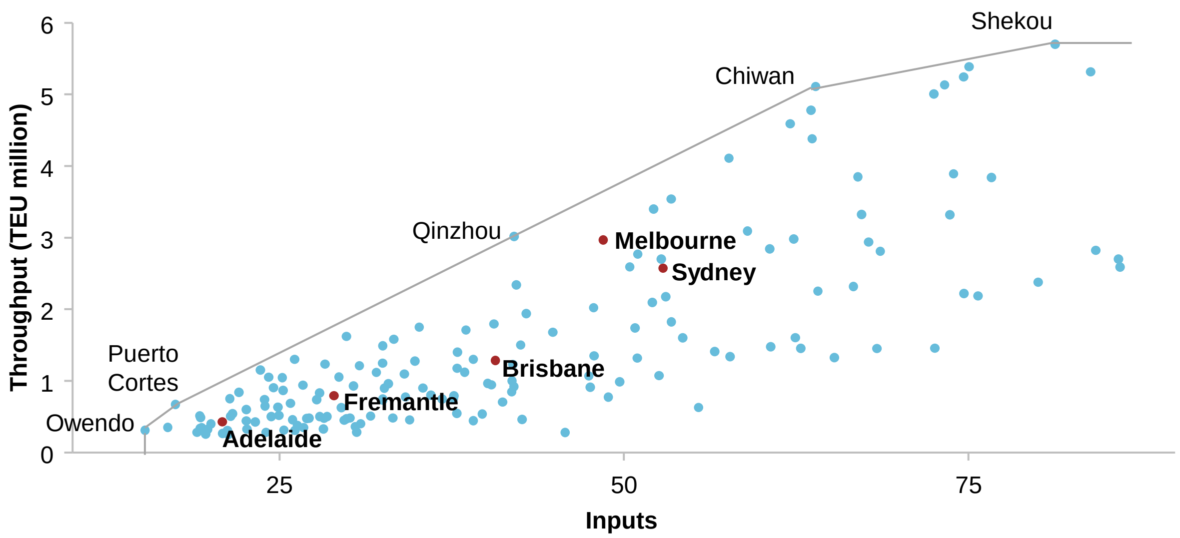
- reduce level of inputs and achieve the same output (also to reduce slack in inputs)
- investigate the operations of peer ports.

The input-oriented DEA model measures the potential proportionate reduction in input quantity without changing the output quantity. For example, Melbourne has an efficiency score of 0.9 which means that Melbourne could reduce all inputs by 10 per cent to be technically efficient. That is, for example, Melbourne would need to reduce berth length (2.5 km) by 10 per cent (by 0.25 km). Doing this reduction to all inputs in the model gets Melbourne to a point of efficiency called Farrell efficiency (Ji and Lee 2010, p. 270).

[36] Port’s capital investment cycles may affect DEA results. A port may appear inefficient following a capital expansion and appear more efficient when approaching a capital expansion. Capital investment data is unavailable and as such the effect of investment cycles on the results is unknown.

Figure 24 – Scope exists for most Australian container ports to improve their productivity[a,b]

The two-dimensional estimated productivity possibility frontier



a. Adelaide is estimated to be technically efficient (on the frontier), but the two-dimensional nature of this chart depicts Adelaide within the frontier. The production possibility frontier has multiple dimensions that cannot be depicted in a simple chart. **b.** 'Inputs' in the figure is the sum of all input variables in the model.

Source: Commission estimates using IHS Markit's Port Characteristics data.

Looking to 'peer' ports or other efficient ports might provide insights on how to improve the efficiency of Australian ports over the longer term. For example, Australian ports could be compared with the peers identified by the model (table 11) or similar sized ports that are closer to being technically efficient (table 12). Operations at these ports could be compared to Australian ports to potentially identify areas of improvement. Before consulting with these ports, further investigation would be merited to see if they have fixed characteristics that are similar to the Australian ports, such as the type of port (deep water or river or height restrictions), that are not accounted for in the DEA. Differences in these characterises may be factors constraining Australian port efficiency.

Table 12 – Technical efficiency scores of similar sized ports

Scores in parentheses

	First	Second	Third	Fourth
Brisbane (0.71)	Yarimca (0.67)	Da Chan Bay Terminal One (1)	Mawan (1)	Hamad (1)
Sydney (0.75)	Oakland (0.69)	Southampton (1)	Yokohama (0.65)	Yeosu (1)
Melbourne (0.87)	Houston (0.79)	Virginia (0.71)	Qinzhou (1)	Nagoya (0.82)
Adelaide (1)	Lyttelton (1)	Itapoa (1)	Tin Can Island (0.72)	Salerno (1)
Fremantle (0.73)	Trieste (1)	Aqaba (1)	Dublin (0.96)	Algiers (1)

Source: Commission estimates using IHS Markit's Port Characteristics data.

New Zealand ports are often compared to Australian ports and the model shows they have higher technical efficiency scores. Three NZ ports in the model are estimated to be fully technical efficient: Tauranga, Lyttelton and Napier. Auckland also received a high score of 0.9. This suggests that there might be scope to learn from these ports, especially the larger ones like Tauranga.

Further investigation of peer ports is needed before drawing conclusions about whether and how Australian ports can learn from them.

Caveats on main results

The potential efficiency gains suggested by the Commission's preliminary benchmarking exercise should be interpreted cautiously.

- Investigations into the port characteristics data suggested that there are some inconsistencies with data found on port authority websites. Data for a significant number of ports has been verified (those ports on the frontier and those identified as peers), but further data verification is desirable.
- The performance of each port is based only on the inputs included in the DEA model; missing inputs may bias results. There are characteristics of ports that affect efficiency that cannot always be accounted for. For example, the port of Chattogram in Bangladesh, a potential peer of both Sydney and Melbourne, used their general terminal to move containers as well as their dedicated container terminals. Container ships docking at the general terminal also typically used on-board cranes to move containers. As such, the port appears very efficient because it moved many containers with few inputs (as the general terminal did not factor into the inputs of the model). More investigation would be required to check how the peer ports differ from the Australian ones.
- The potential technical efficiency gains suggested by the model might not always be achievable. For example, there may be factors that constrain Australia's port productivity relative to the international ports that are outside the control of the port (such as infrequent ship visits).
- Australian ports might operate below the frontier and underutilise capacity to prevent port congestion and cope with seasonality in demand (peaks in container volumes and ship arrivals, see chapter 2, inquiry report). Reducing the level of inputs could lead to greater inefficiencies, such as increasing ship turnaround times. This suggests there may be an optimal level of asset utilisation that strikes a balance between technical efficiency and turnaround times (and potentially cost minimisation).
- Changes in technical efficiency over time are not examined. The time-series data needed to support such analysis are not available. Improvements in the technical efficiency scores of Australian ports over time would be reassuring, whereas a deteriorating trajectory would provide reason for concern.

It is also important to recognise that the Commission's benchmarking exercise differs from the World Bank's and, as such, the performance ranking of Australian ports does too. For example, Adelaide is ranked in the top 1 per cent for technical efficiency but bottom 25 per cent in the World Bank study. The World Bank's benchmarking analysis did not account for the fact that some ports have relatively more inputs and can use those inputs to turn ships around faster (while the Commission's analysis does not take *time* into account). For example, the port of Yokohama, which topped the World Bank rankings, had a technical efficiency score (0.65), which is lower than all the Australian ports. Yokohama had the fastest ship turnaround times as indicated by the CPPI and higher gross crane rates, but they also had five container terminals, about 5.5 km of berths and about 40 quay cranes. In comparison, Melbourne and Sydney each had three terminals, about 2.5 to 3.6 km of berths and about 20 quay cranes each. Yokohama allocated more cranes to unload ships on average than Australian ports (figure 3.16). Given Yokohama had similar yearly throughput to Melbourne and Sydney, Yokohama's capital utilisation was much lower, which reduced their technical efficiency, but helped them achieve faster turnaround times and might enable them to better cope with any increase in the volume of containerized trade.

Sensitivity analysis

To test the robustness of the DEA results for Australian ports several sensitivity tests were undertaken.[37] These involved altering the input variables or specification of those variables and different sample restrictions.

- Excluding the number of terminals as an input (table 13, column 2). This variable is used to proxy the level of competition in a port on the grounds that greater competition might produce greater efficiency in the use of inputs, but it is rarely included in the literature.
- Not differentiating the types of quay cranes (column 3). That is, including one variable of the number of cranes, rather than three.
- Replacing berth length and number of berths with average berth length (column 4). This is because there is a high degree of correlation between these variables which can introduce bias into the model.
- Replacing berth length, number of berths and number of gantry cranes with average number of gantry cranes per kilometre (column 5). This is because there is a high degree of correlation between these variables which can introduce bias into the model.
- Running two separate DEA models for ports above and below the average throughput of the sample (1.5 million TEUs) (column 6). Under this definition, Melbourne and Sydney are above average size, and Brisbane, Fremantle and Adelaide are below average size.

The sensitivity analysis suggests that the DEA results are sensitive to some modelling choices but not all (table 13). The technical efficiency scores from the preferred VRS specification from table 13 are also presented to allow for comparison (column 1). Each model assumes variable returns to scale. A few notable differences include:

- when excluding the number of terminals as an input, the results are relatively robust however Adelaide is no longer technically efficiency (column 2)
- reducing the multicollinearity in the model reduces the technical efficiency scores of most ports, with the exception of Adelaide (columns 4 and 5).

Table 13 – Most Australian ports have scope for improvement [a]

Technical efficiency scores for Australian ports

Port	Preferred specification (1)	Excluding terminals (2)	Number of cranes (3)	Avg berth length (4)	Avg gantry cranes per berth km (5)	Sample split by size (6)
Adelaide	1.00	0.91	1.00	1.00	1.00	1.00
Melbourne	0.90	0.90	0.89	0.86	0.78	0.93
Sydney	0.75	0.75	0.75	0.79	0.78	0.76
Fremantle	0.73	0.73	0.71	0.74	0.66	0.75
Brisbane	0.71	0.71	0.71	0.75	0.72	0.81

a. Variable returns to scale models were used to account for differences in throughput levels and economies of scale.

Source: Commission estimates using IHS Markit's Port Characteristics data.

[37] DEA results are sensitive to the size of the sample used. Smaller samples tend to result in more ports being identified as technically efficient (Cullinane 2010, p. 923). Given the large sample size used here this is unlikely to be an issue.

8. Summary

The number of containers that pass through Australian ports reflects the demand for imports by the wider community and world demand for Australian exports.

Australian ports are primarily destination ports — they import more full containers than they export. This differentiates them from many overseas ports, particularly transhipment ports like Singapore and, to some extent, from origin ports like Shanghai.

The number of ships handled at Australian ports has increased over the long term as has the volume of cargo handled. However, the higher rate of growth in the number of containers handled has meant that the average call size — the average number of containers handled per ship visit — has also increased. This means that Australian ports are not only handling bigger ships but that they have relatively more cargo to unload and load on each visit.

Adelaide and Fremantle generally performed well across a range of quayside and landside operations productivity-related metrics. These two ports also had the highest net crane rates in 2019. They used fewer cranes on average than the other ports but worked them harder. And published truck turnaround times were fastest in Fremantle, while Adelaide recorded higher truck utilisation perhaps resulting from a lower share of exported empty containers in their system relative to other states (chapter 2) and likely because there is a single terminal operator to transport containers to and from.

Of the bigger ports, Melbourne performed well on many quayside and landside measures. Melbourne moved more containers per hour than any other Australian port, owing to its use of more cranes per ship. Sydney and Brisbane, on the other hand, appear to have some scope to improve their truck turnaround times. That said, some participants were adamant that turnaround times in Australian ports were among the best in the world.

Quayside productivity varied across terminal operators within a port and, for each operator, over time. This suggests that there is scope for all terminal operators to improve the consistency, and therefore level, of their performance.

Ship turnaround times point to potential areas for improvement. The fact that ships in Sydney and Melbourne spent longer in port (42 hours and 36 hours, respectively) is unsurprising; they are bigger ports and handle more container movements, giving rise to longer operating times — the main component of port hours. Ships appeared to have longer average anchorage times in Sydney and Brisbane. Further information on why ships are anchoring would help to uncover whether longer anchorage times are a result of port congestion, port inefficiency or external factors (such as ships missing windows). Addressing time spent at anchorage should be an easy way to improve port performance.

While the Australian data is not well suited to assessing long-run trends in Australian container ports, the available data points to the quayside productivity at *all* Australian ports having grown since late 1989. Growth in crane and ship rates was strongest in the late 1990s following significant waterfront reforms. Since then, growth rates have been lower. However, the fact that Australian ports are handling larger containers and the crane rate (in terms of the number of containers) has been relatively stable points to productivity improvements in terms of the quantity of goods being moved though the ports. Ports are also using more cranes to service ships and as such the ship rate has continued to improve.

Benchmarking is a useful exercise but it is also a challenging one. Different methods, samples, and data can produce different results, while focusing on different aspects of efficiency (physical inputs and outputs as opposed to time) make it difficult to reconcile why the performance of individual ports may differ across studies. Further, most international benchmarking has focused on performance on the marineside and quayside. This means landside performance, which is a critical part of the supply chain, is excluded.[38]

These challenges make it difficult to identify concrete ways of improving port-wide efficiency, but comparisons across different types of studies can yield some powerful insights. For example, unpacking the results of the World Bank study revealed that Australia could improve turnaround times for large ships by reducing anchorage and operating times (by allocating more cranes to these ships where feasible). It also revealed that Australian ports have similar gross crane rates to the average global port — in other words, Australia's major container ports do not rank poorly in the World Bank analysis because ports move fewer containers per crane while ships are being worked — but used fewer quay cranes on average to handle containers. The Commission's benchmarking analysis showed that Australian container ports could utilise their physical inputs more intensively (and improve their technical efficiency), but data limitations mean the analysis cannot shed light on ways in which productivity might be improved in the short to medium term.

Although there were criticisms of the Commission's analysis (Toner 2022, commissioned by the Maritime Union of Australia), the results found here are broadly consistent with other empirical studies of port productivity (outlined in the literature review in appendix C) — Australian container ports are generally less efficient than their international counterparts on many dimensions (notably slower ship turnaround times and inefficient use of their capital inputs). The limitations of the Commission's approach and data have been acknowledged the technical paper, with the interpretation of results qualified where necessary.

Future work might seek to build upon the World Bank and the Commission's benchmarking analyses by combining time-based metrics (from the Port Performance Program) and port characteristics into one dataset (provided there is further verification of the characteristics data). The resulting comprehensive dataset would enable port performance to be analysed while controlling for port characteristics (such as call sizes, ship sizes, length of berths, geography, landside interface and types of port) using regression techniques. This could allow analysts to uncover the key drivers of performance (or turnaround times). The Commission did not undertake this work for this inquiry given concerns noted above about the validity of the port characteristics data.

On balance, the empirical evidence suggests that there is scope for Australian container ports to improve their productivity.

[38] As noted in section 6, DP World submitted evidence that container dwell times in their Australian terminals are lower than in their international terminals, suggesting Australians landside performs well in an international context.

Appendices

A. Data sources

BITRE data

The Bureau of Infrastructure and Transport Research Economics (BITRE) publishes data on the performance of Australian container ports in their *Waterline* publication.

Waterline was first published in July 1994, initially on a quarterly basis. It is now published on an irregular basis. The latest issue, *Waterline 67*, was published in December 2021 and contains data through to December 2020, with some commentary on the statistics and on recent developments.

The recent *Waterline* reports consist of four sections:

- measures of container terminal throughput
- measures of container terminal productivity
- vehicle booking system and empty container park operations
- port interface cost index (used by the ACCC).

A range of indicators are published within these sections (table A.1). These indicators are published for the five main container ports in Australia (Brisbane, Sydney, Melbourne, Adelaide and Fremantle) and a 'five ports' total. Numerous metrics are expressed on both a container and twenty-foot equivalent (TEU) basis.

The range of reported indicators has changed over time. The number of indicators has expanded, and some metrics have been renamed and refined (so they are not consistent over time). Earlier editions included some discussion of employment and labour market issues; recent issues do not.

The duration of time series data varies by indicator. The crane rate, elapsed labour rate and ship rate span the longest period (1989–2020), enabling a longer-term assessment of quayside productivity. Other measures have much shorter time series which limit their usefulness for examining long-term trends. For example, metrics such as truck turnaround time, anchorage time and ship turnaround time only span 2011–2020.

IHS Markit data

Port Performance Program data

IHS Markit's Port Performance Program started in 2009 with the goal of driving efficiency improvements in container port operations and supporting programs to optimize port calls. This unique and highly comprehensive dataset covers:

- data from 10 of the world's largest liner shipping companies, which collectively operate 76 per cent of global fleet capacity
- 502 ports and 1014 terminals in 137 countries, with calls by 3860 individual vessels
- more than 180 000 port calls per year
- the calendar years 2017 to 2021 (with data collection continuing).

Table A.1 – Summary of recent *Waterline* indicators[a]

Throughput	Productivity	VBS / ECP operations	Port interface cost index
Number of ships handled	Net crane rate	Number of truck timeslots available	Total ship-based charges by ship visit
Total containers handled	Net elapsed labour rate	Number of truck timeslots used	Total ship-based charges for handling empty containers
40-foot containers (%)	Net ship rate	Timeslots used in off-peak periods	Ship-based charges (conservancy; tonnage; pilotage; towage; un/mooring; total)
Number of trucks	Containers per berth meter	TEUs handled per VBS/TAS truck timeslot (average)	Cargo-based charges (wharfage; harbour dues)
Number of containers transported by truck/rail/joint	Containers per truck	Number of containers moved through ECPs	Other charges (stevedoring – wharfside; stevedoring – landside; terminal access charge; customs broker; total)
Total cargo throughput	Backloading of trucks (%)		
Non-containerised general cargo throughput	Truck turnaround time (average)		
Number of full container imports and exports	Container turnaround time (average)		
Number of empty container imports and exports	Ship turnaround time (median; 95th percentile)		
	Ships at anchorage (number; %)		
	Time at anchorage (average; median)		
	Total berth hours		
	Total time ship available to stevedores		
	Lifts per ship-hour at berth (average)		
	Lifts per hour of stevedoring operation (average)		
	Lifts per berth visit (average)		

a. VBS = vehicle booking system. ECP = Empty Container Parks. TAS = truck appointments system.

Source: BITRE (2021).

The individual port call data are aggregated to monthly level data for each terminal within a port, for a given ship and call size.

Member shipping lines provide port call data to IHS Markit on a monthly basis. The data undergo a thorough checking and validation process including:

- the removal of records falling outside well-defined data quality boundaries because those observations usually exist as a result of data input errors
- the matching of ship data to AIS historical vessel movements data to track and verify each individual ship call.

Table A.2 shows the variables included in the data.

All metrics are standardised (that is, calculated the same way) to enable a fair comparison across ports.

Table A.2 – Variables in the Port Performance Program, 2020[a,b]

Time-based metrics	Port performance	Port characteristics
Anchorage time (hours)	Port moves per hour	Call size
Steam-in (hours)	Berth moves per hour	Ship size
Arrival process (hours)	Gross crane rate	
Start (hours)	Crane intensity	
Cargo operations (hours)	Minutes per container move	
Finish (hours)	Per cent of anchored calls	
Port hours		
Berth hours		
Gross crane hours		

a. The Commission understands that IHS Markit are currently collecting data on throughput and dwell time in port to be incorporated in the next iteration of the CPPI.

Source: IHS Port Performance Program data.

Sampling

There are missing data in the Port Performance Program. For example, for a given ship call there may be missing data regarding anchorage times, operating times or gross crane hours. This is sometimes a result of IHS Markit not being able to verify the data using AIS or because the data provided were outside the data quality boundaries.

The Commission's analysis uses observations with complete data for the measure presented in each chart. This means that the sample size differs across charts depending on the metric presented. This was done to ensure the maximum number of observations were used. The variable that had the most missing data was gross crane hours (about 40 per cent of all observations), therefore the charts that use this variable (such as gross crane rates) have the smallest underlying sample size.

How representative are the Port Performance Program data?

As noted above, the Port Performance Program is based on information from 10 of the world's largest shipping lines. Because this is a sample, there is no guarantee that every ship call at Australia's major container ports is captured in the data (that is, there may be ships from out-of-sample shipping lines calling). This raises a question about how representative the data are of Australian ports.

To address this question, a selection of metrics from *Waterline* and the Port Performance Program were compared (table A.3). Approximately 80 per cent of port calls to Australian ports are covered in the IHS data, suggesting relatively good coverage. The average call sizes are extremely close across the data sets, suggesting that while there is not full coverage of ships visiting the ports, on average the ships in the sample are representative of a typical port call. Ship turnaround times are also similar for most ports. The exceptions are Sydney and Adelaide in which median turnaround times appear longer in the Port Performance Program data. The discrepancy is a result of Sydney and Adelaide port operators providing *Waterline* with a 'port hours' measure that excludes anchorage, steam-in and steam-out times. That is, the *Waterline* data for Sydney and Adelaide report berth hours rather than port hours. Median berth hours for these ports are almost identical across datasets (32.2 hours in *Waterline* compared to 32.8 hours in the Port Performance

Program data for Sydney, and 21.8 hours compared to 21.7 hours for Adelaide).[39] This provides us with greater confidence that the Port Performance Program data is representative.

Table A.3 – Port Performance Program data cover around 80 per cent of ship calls in Australian ports[a]

Various metrics from *Waterline* and Port Performance Program data, 2019

Measure	Brisbane	Sydney	Melbourne	Adelaide	Fremantle
Number of ship calls					
Waterline	973	1158	1010	425	483
Port Performance Program	718	861	783	367	402
Per cent	74%	74%	78%	86%	83%
Average call size (containers)					
Waterline	846	1423	1684	709	1095
Port Performance Program	892	1470	1695	731	1086
Median ship turnaround time (hours)					
Waterline	30.2	32.2	38.4	21.8	31.2
Port Performance Program	29.7	40.1	36.3	30.8	32.8
95th percentile of ship turnaround time (hours)					
Waterline	55.8	65.0	64.3	37.0	54.7
Port Performance Program	54.4	90.3	64.3	49.1	54.9

a. There are limited comparable metrics between BITRE's Waterline data and IHS Markit's Port Performance Program data.

Source: BITRE (2021) and IHS Markit's Port Performance Program data.

Port characteristics data

IHS Markit's Bespoke Maritime Data Services unit maintains the largest maritime databases available, covering ship characteristics, movements, owners and managers, ship and company sanctions compliance, casualty and risk events, ports, terminals and berths.

The Commission purchased data covering almost 1500 ports that receive containers including details of:

- ports — such as throughput, location, maximum port restrictions and port facilities
- terminals — such as name, terminal operator, facility type and location
- berths — such as name, operator, facility type, location, physical dimensions, maximum berth restrictions (beam, depth, weight) and tidal information
- berth cranes — such as crane type and use, quantity and maximum outreach.

The data also provide information on when the data were last updated.

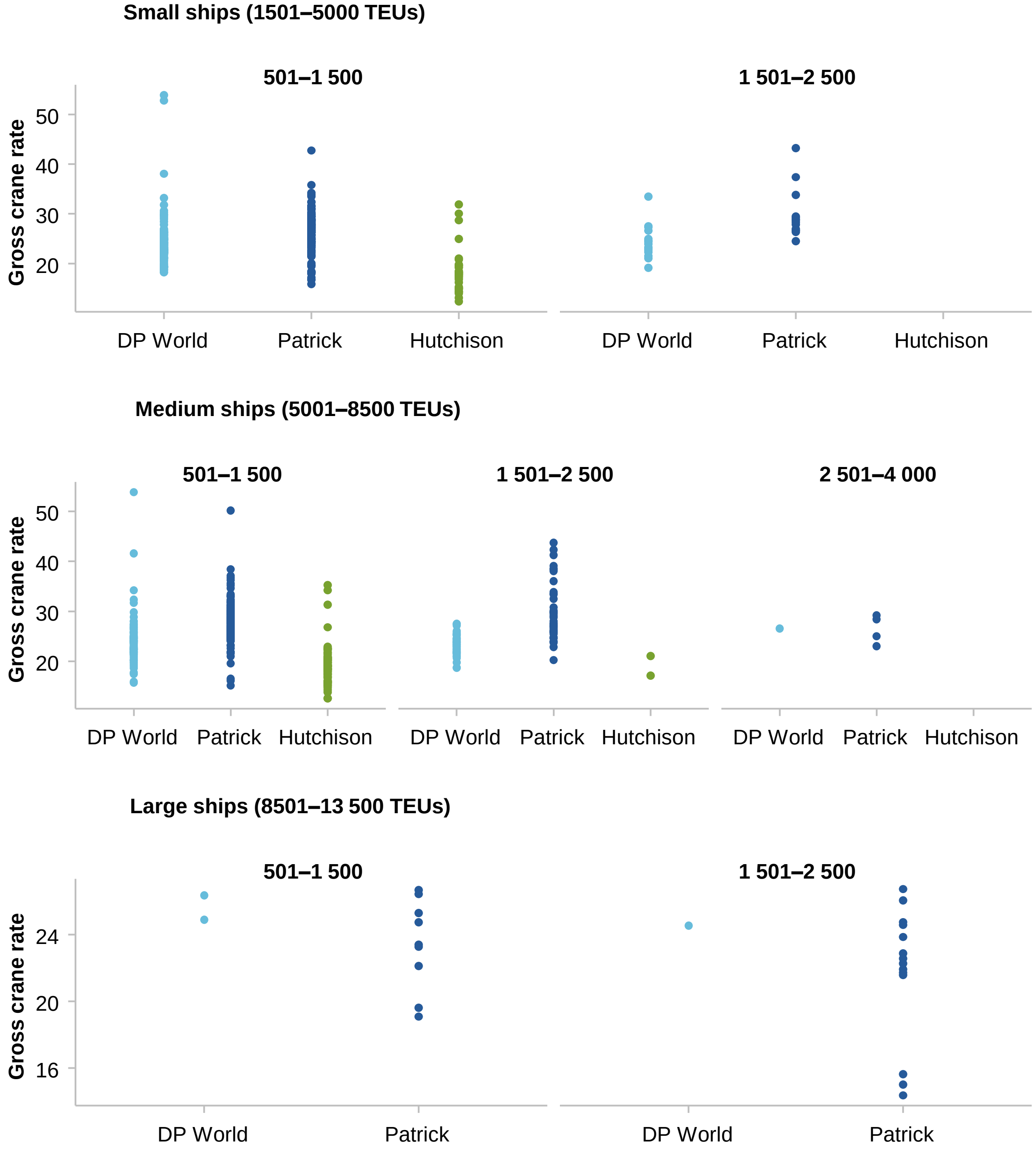
[39] The 95th percentiles of berth hours are also close. Sydney is 65.0 (*Waterline*) compared to 67.6 (Port Performance Program) and Adelaide is 37 (*Waterline*) compared to 38.9 (Port Performance Program).

B. Supplementary figures and tables

Gross crane rates for terminal operators

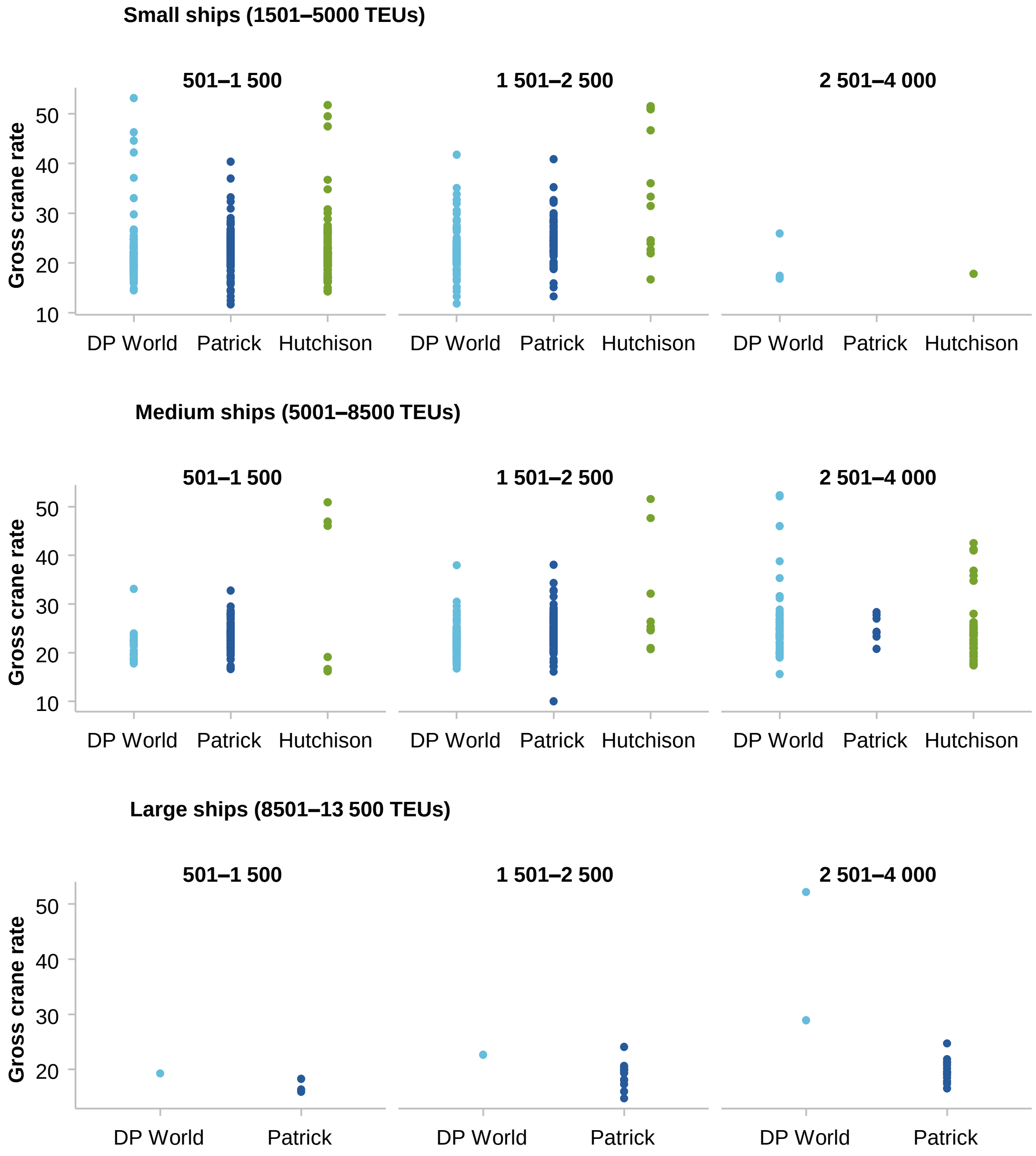
This section presents charts that depict the variability in gross crane rates. Each chart plots individual observations of gross cane rates by ship and call size groups for terminal operators observed in the Port Performance Program data between 2017 and 2020.

Figure B.1 – Gross crane rates by ship and call size groups, Brisbane, 2017–2020



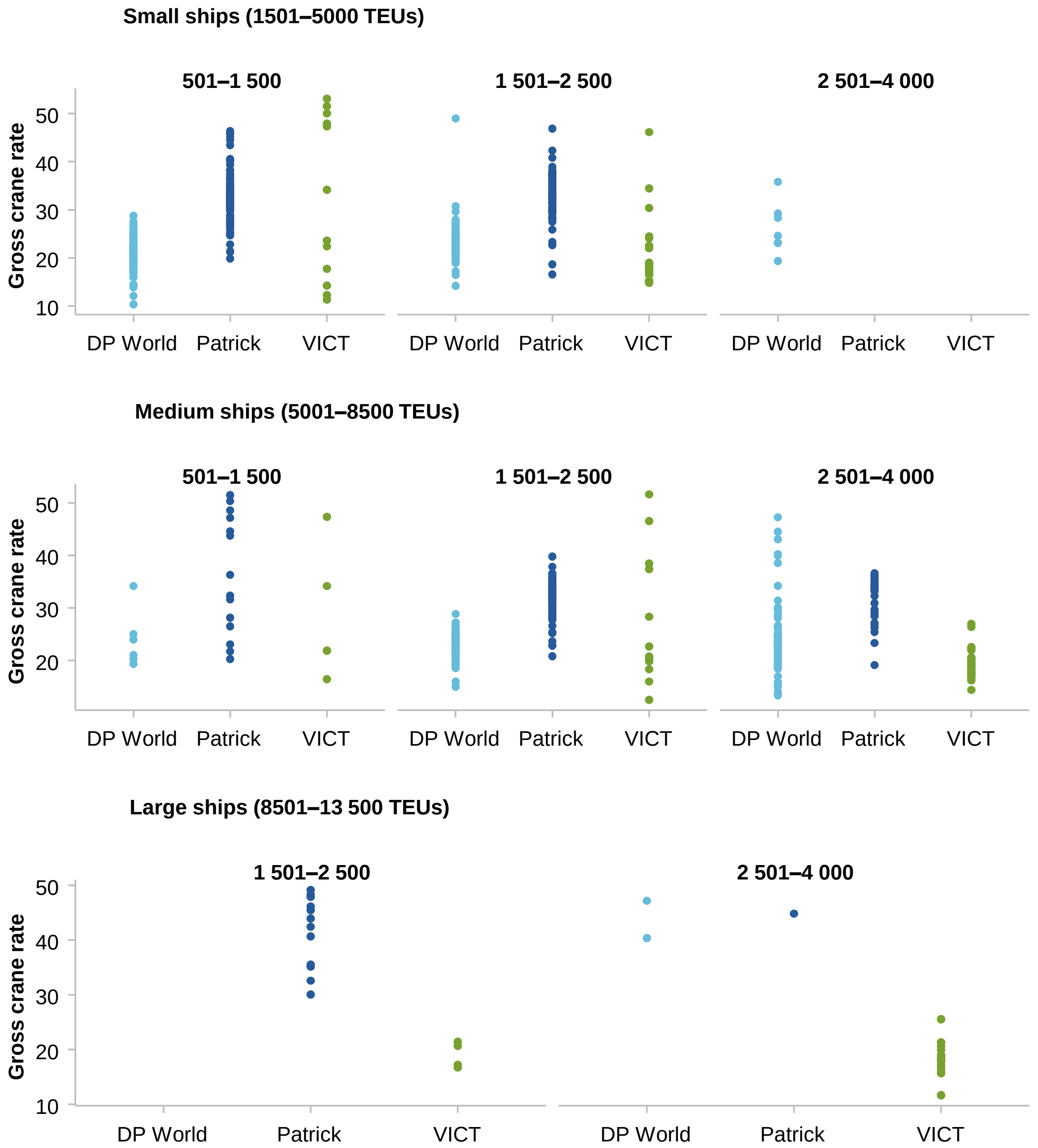
Source: IHS Markit's Port Performance Program data.

Figure B.2 – Gross crane rates by ship and call size groups, Sydney, 2017–2020



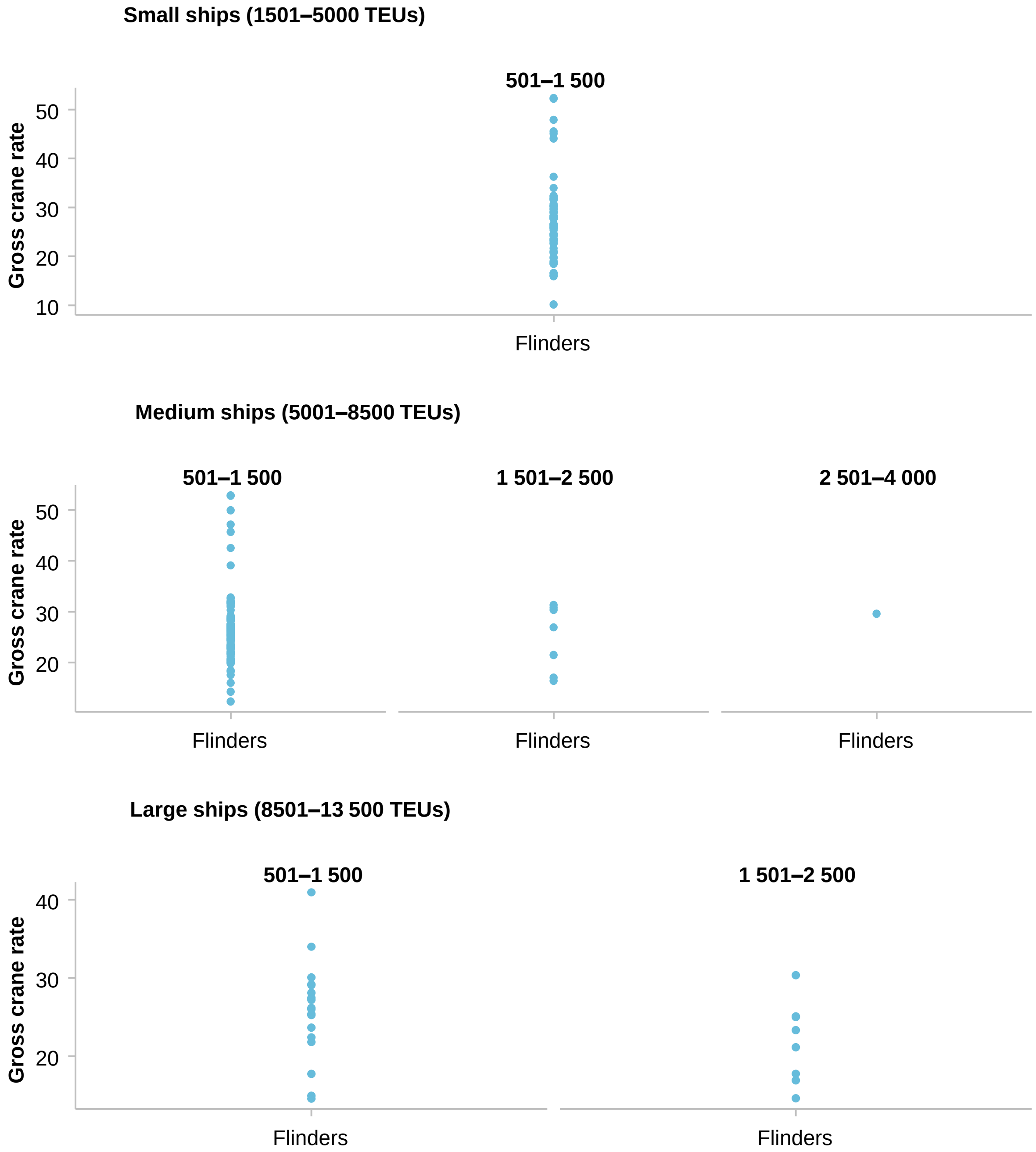
Source: IHS Markit's Port Performance Program data.

Figure B.3 – Gross crane rates by ship and call size groups, Melbourne, 2017–2020



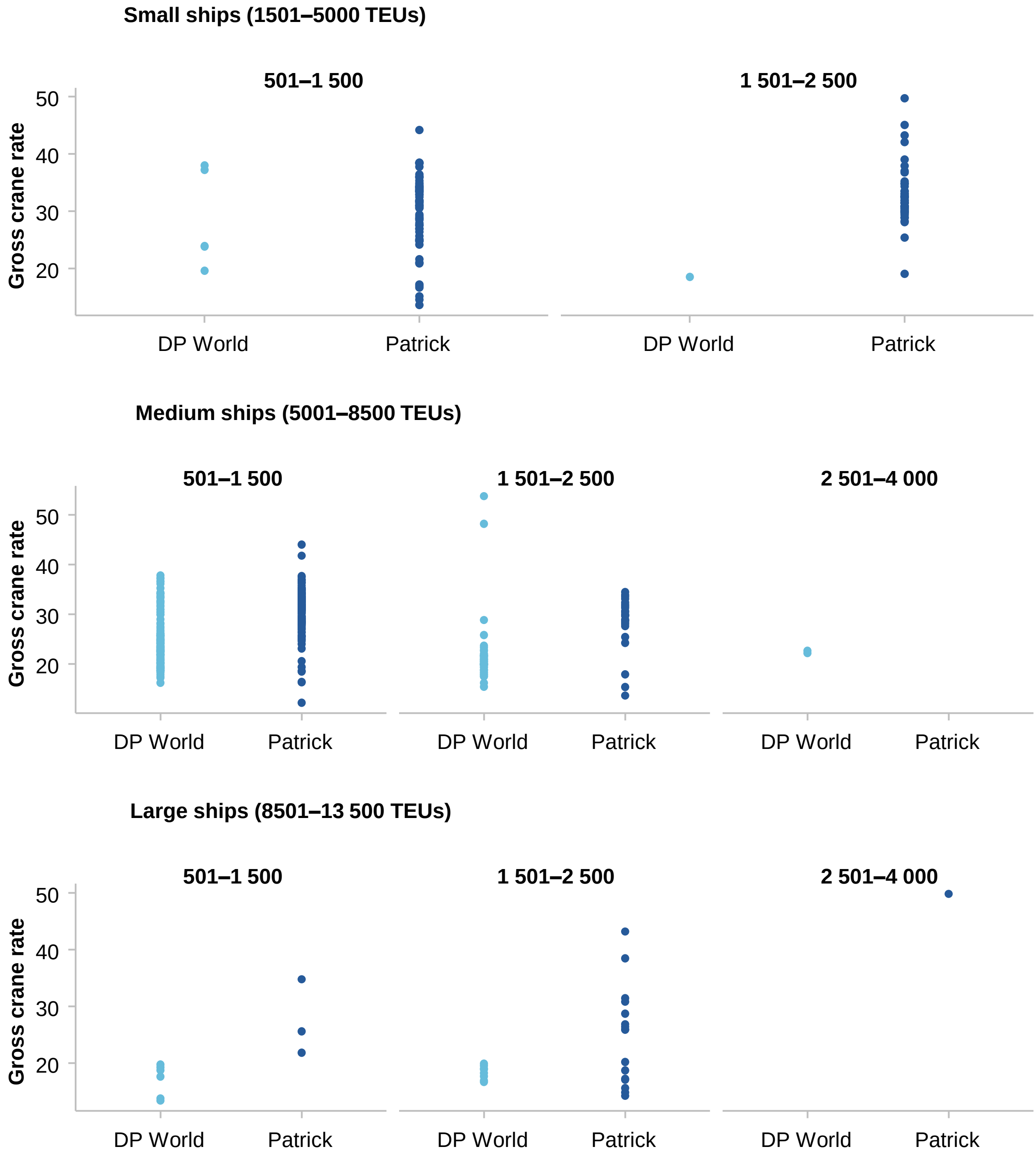
Source: IHS Markit's Port Performance Program data.

Figure B.4 – Gross crane rates by ship and call size groups, Adelaide, 2017–2020



Source: IHS Markit's Port Performance Program data.

Figure B.5 – Gross crane rates by ship and call size groups, Fremantle, 2017–2020



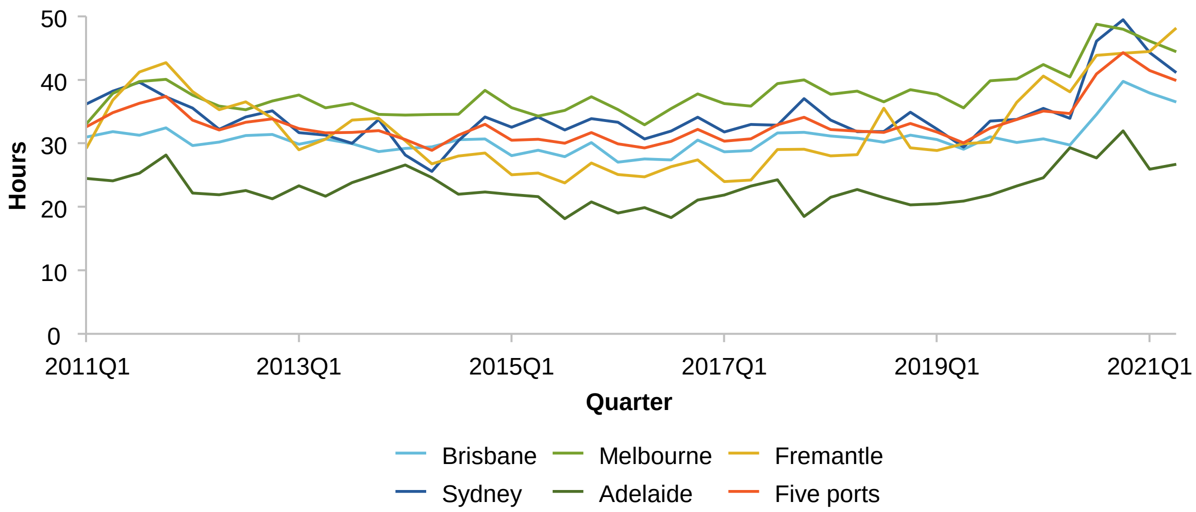
Source: IHS Markit's Port Performance Program data.

Long-term trends

This section presents 'longer term' trends for selected measures of port performance. The analysis relies on *Waterline* data.

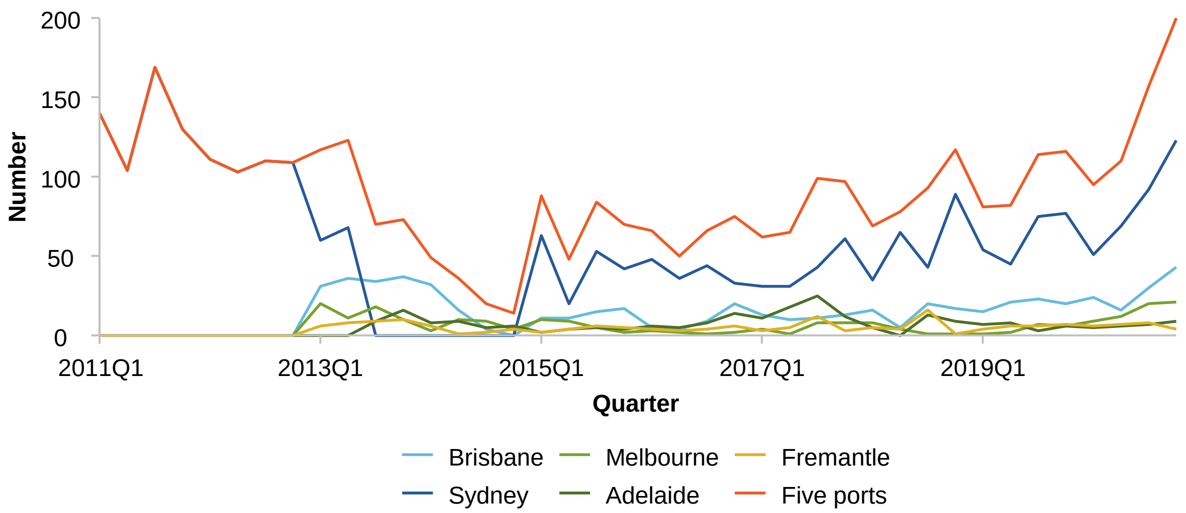
Port operations

Figure B.6 – Median ship turnaround time, 2011–2021



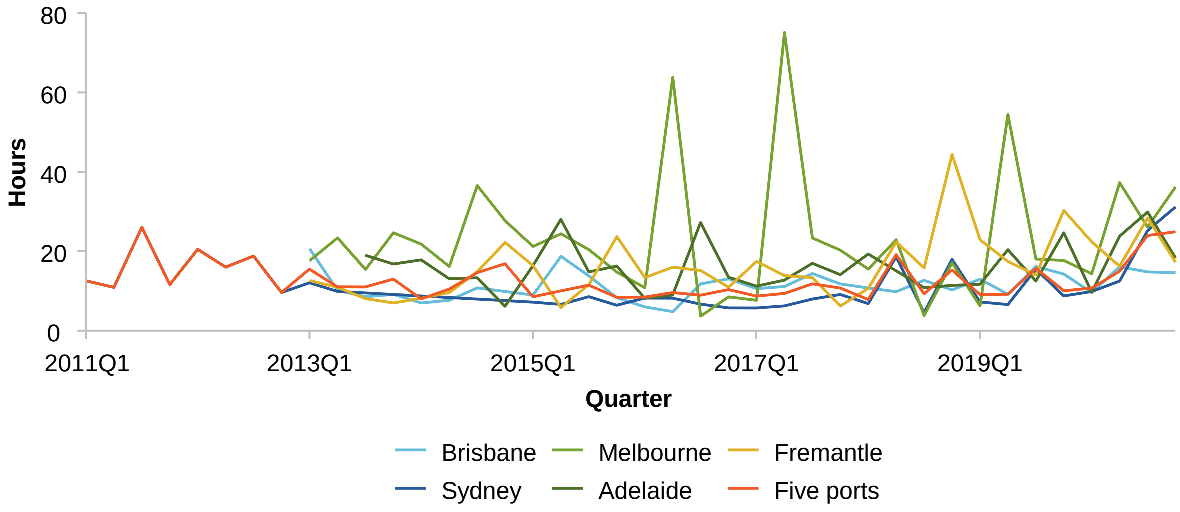
Source: BITRE *Waterline* (various editions).

Figure B.7 – Number of ships waiting at anchor for more than 2 hours, 2011–2021



Source: BITRE *Waterline* (various editions).

Figure B.8 – Median waiting time at anchor, 2011–2021[a]



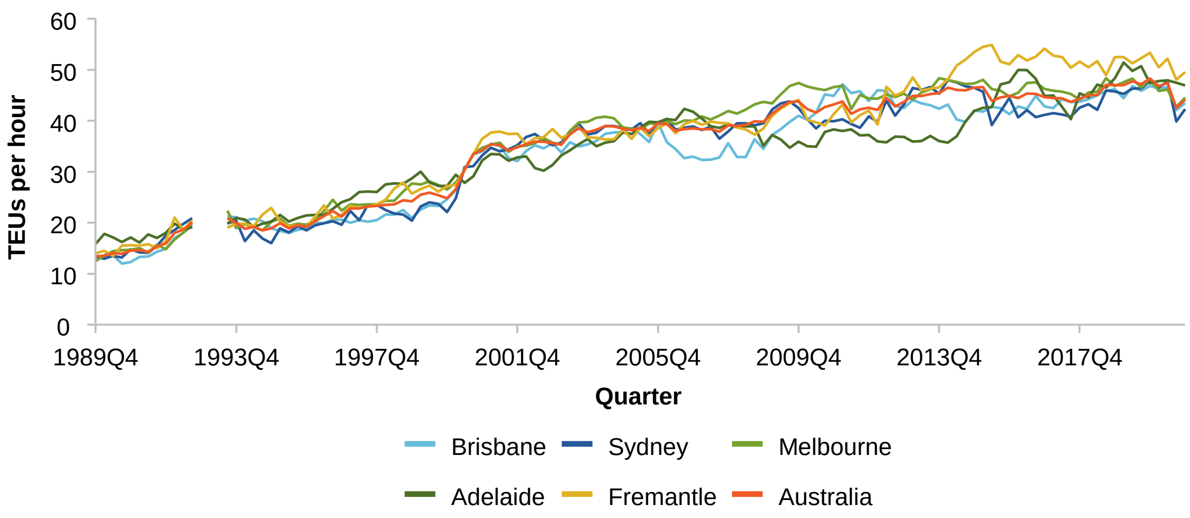
a. Only ships that waited more than 2 hours at anchorage are included in the calculation.
Source: BITRE *Waterline* (various editions).

Quayside operations

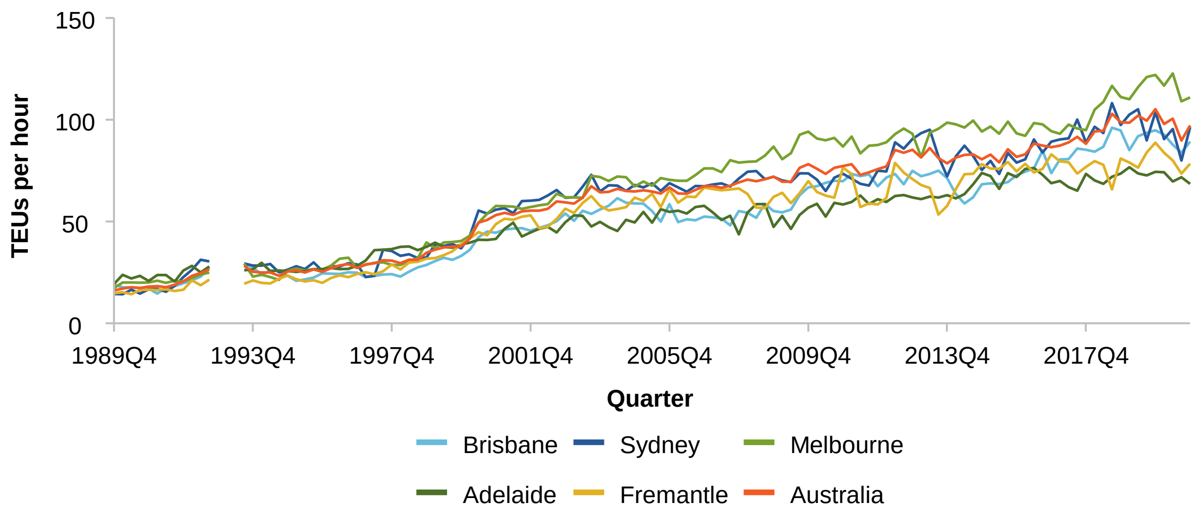
Figure B.9 – Long-term productivity has risen in *all* Australian ports[a]

TEUs per hour, 1989Q4 to 2020Q4

a) Net crane rates



b) Net ship rates



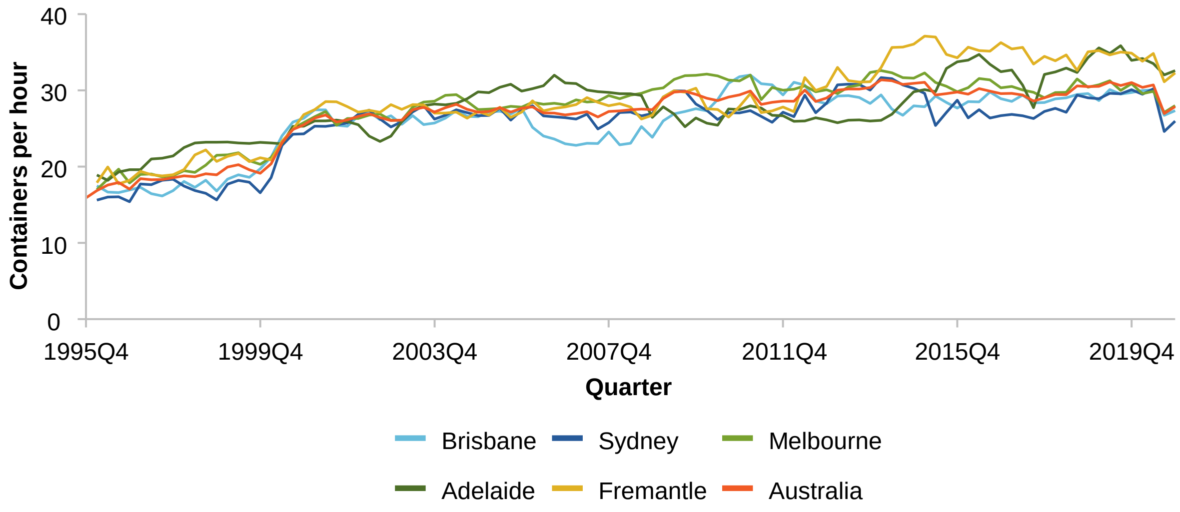
a. Data for both crane and ship rates were not published between 1992Q4 and 1993Q2.

Source: BITRE *Waterline* (various editions).

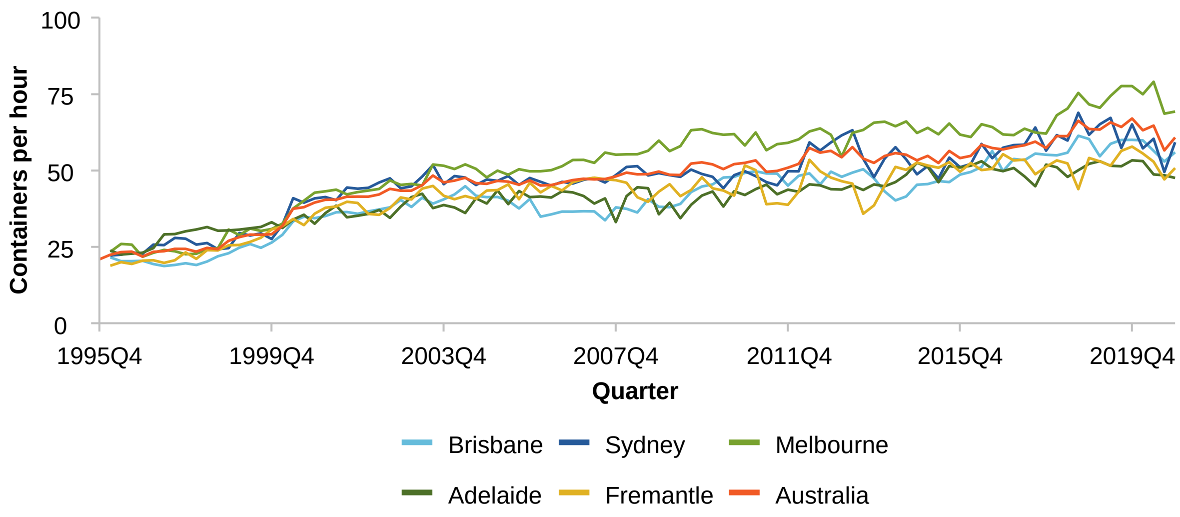
Figure B.10 – Long-term productivity has risen in *all* Australian ports[a]

Containers per hour, 1995Q4 to 2020Q4

a) Net crane rates



b) Net ship rates

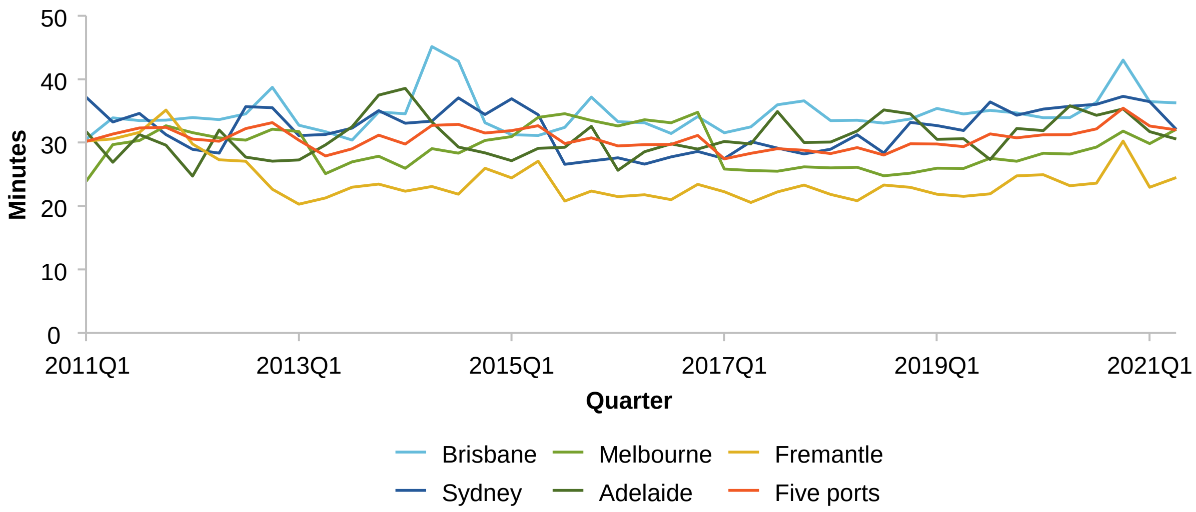


a. Data for both crane and ship rates were not published between 1992Q4 and 1993Q2.

Source: BITRE *Waterline* (various editions).

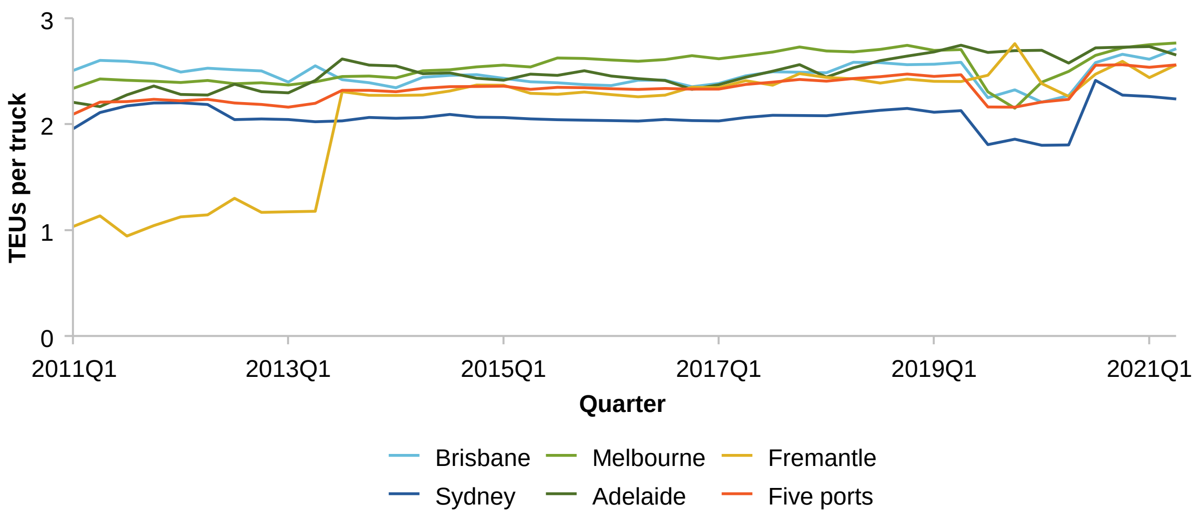
Landside operations

Figure B.11 – Truck turnaround times, 2011–2021



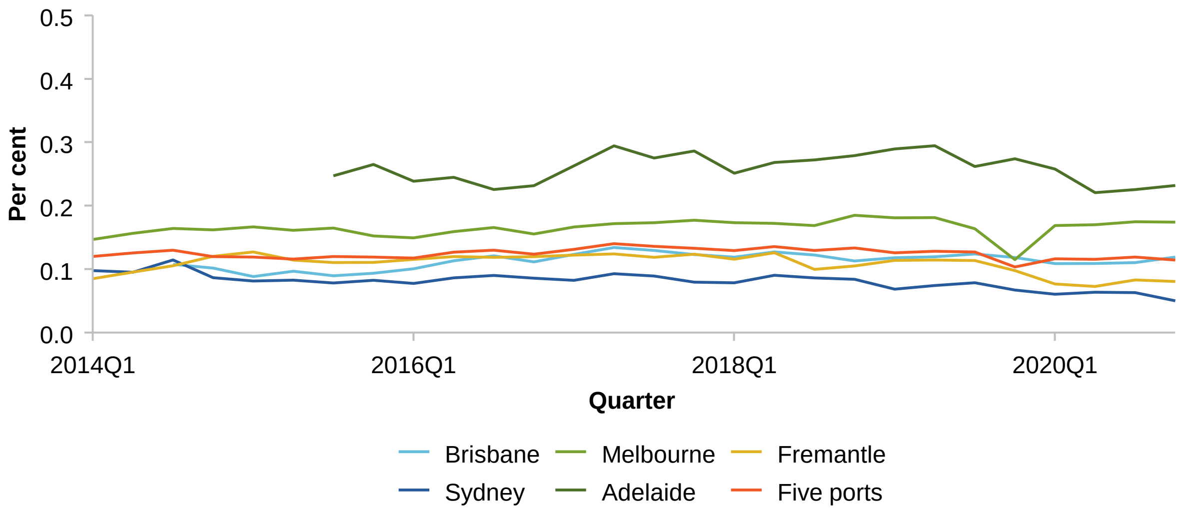
Source: BITRE *Waterline* (various editions).

Figure B.12 – Truck utilisation rates, 2011–2021



Source: BITRE *Waterline* (various editions).

Figure B.13 – Proportion of trucks backloaded, 2014–2019



Source: BITRE *Waterline* (various editions).

DEA modelling: additional results

Table B.1 – Technical efficiency scores for all ports[a,b]

Port	CRS model	VRS model
Aarhus	0.50	1.00
Abidjan	0.51	1.00
Adelaide	0.62	1.00
Aguadulce (Colombia)	0.71	1.00
Algiers	1.00	1.00
Aqaba	0.62	1.00
Ashdod	0.41	0.67
Auckland	0.66	0.90
Baltimore (Usa)	0.37	0.66
Bangkok	0.37	1.00
Barcelona	0.95	0.96
Batangas	0.94	1.00
Beira	0.31	1.00
Beirut	0.51	1.00
Bejaia	0.39	1.00
Belawan	0.32	1.00
Bilbao	0.26	0.35
Boston (Usa)	0.31	1.00
Brisbane	0.53	0.71
Buenaventura	0.37	0.68
Cai Mep	0.78	0.87
Callao	0.90	0.92
Cape Town	0.62	1.00
Cat Lai	1.00	1.00
Charleston	0.57	0.75
Chattogram	1.00	1.00
Chiwan	1.00	1.00
Colon	0.92	0.93
Da Chan Bay Terminal One	0.62	1.00
Dakar	0.34	1.00
Damietta	0.51	1.00
Dammam	0.49	0.69

Port	CRS model	VRS model
Dar Es Salaam	0.38	1.00
Davao	1.00	1.00
Djibouti	0.36	0.53
Douala	0.51	1.00
Dublin	0.50	0.96
Dunkirk	0.44	1.00
Durban	0.75	0.81
El Dekheila	0.43	0.59
Felixstowe	0.88	0.88
Fremantle	0.56	0.73
Fuzhou	1.00	1.00
Gdansk	0.93	1.00
Gdynia	0.48	0.73
Genoa	0.62	0.75
Gothenburg	0.37	1.00
Guayaquil	0.38	0.93
Halifax	0.25	0.55
Hamad Port	1.00	1.00
Houston	0.74	0.79
Incheon	0.80	0.80
Iquique	0.34	1.00
Itajai	0.99	1.00
Itapoa	0.41	1.00
Jacksonville	0.37	0.77
Jawaharlal Nehru Port	0.92	0.92
Johor	0.83	1.00
Karachi	0.50	0.63
Keelung	0.31	0.69
Khalifa Port	0.47	0.65
King Abdullah Port	0.62	0.70
Klaipeda	0.49	0.72
Kobe	0.45	0.71
Koper	0.75	1.00
Kotka	0.46	1.00
La Spezia	0.47	0.70

Port	CRS model	VRS model
Lagos (Nigeria)	0.60	1.00
Lazaro Cardenas	0.43	0.66
Le Havre	0.47	0.49
Leixoes	0.62	0.85
Lianyungang	1.00	1.00
Limassol	0.30	1.00
Lirquen	0.59	1.00
Livorno	0.40	0.81
Lome	0.69	0.75
London	0.71	0.82
Lyttelton	0.49	1.00
Manila	1.00	1.00
Mariel	0.39	1.00
Marseille	0.44	0.50
Mawan	0.69	1.00
Melbourne	0.87	0.90
Mersin	1.00	1.00
Miami	0.47	0.70
Mobile	0.28	0.70
Moji	0.34	0.86
Mombasa	0.60	0.78
Montreal	0.59	0.96
Muhammad Bin Qasim	0.63	0.82
Mundra	1.00	1.00
Nagoya	0.70	0.82
Naha	0.79	1.00
Napier	0.86	1.00
Naples	0.75	0.80
Nemrut Bay	0.29	0.64
New Orleans	0.61	1.00
Novorossiysk	0.40	0.57
Oakland	0.46	0.69
Odessa	0.27	0.73
Osaka	0.59	0.79
Owendo	1.00	1.00

Port	CRS model	VRS model
Papeete	1.00	1.00
Paranagua	0.74	1.00
Penang	0.72	1.00
Philadelphia	0.18	0.79
Pipavav	0.87	1.00
Port Everglades	0.82	1.00
Port Louis	0.32	1.00
Port Of Virginia	0.60	0.71
Port Reunion	0.30	1.00
Posorja	1.00	1.00
Prince Rupert	1.00	1.00
Puerto Cortes	1.00	1.00
Qinzhou	1.00	1.00
Riga	0.42	0.75
Rio De Janeiro	0.31	1.00
Rio Grande (Brazil)	0.68	1.00
Rio Haina	0.63	1.00
Salerno	0.34	1.00
Salvador	0.42	1.00
San Antonio	0.72	0.81
San Juan	0.55	0.82
San Vicente	1.00	1.00
Santo Tomas De Castilla	0.67	1.00
Santos	0.72	0.78
Savannah	1.00	1.00
Seattle	0.28	0.60
Sepetiba	0.25	1.00
Shantou	0.44	0.68
Shekou	1.00	1.00
Shimizu	0.31	0.66
Shuaiba	0.17	1.00
Shuwaikh	0.52	0.96
Sines	1.00	1.00
Sohar	0.36	0.52
Southampton	1.00	1.00

Port	CRS model	VRS model
Suape	0.41	1.00
Sydney	0.69	0.75
Tacoma	0.35	0.68
Taichung	1.00	1.00
Taipei, Taiwan, China	0.80	1.00
Tanjung Perak	1.00	1.00
Tauranga	0.89	1.00
Teesport	0.46	0.64
Tema	0.42	0.54
Tin Can Island	0.37	0.72
Tokyo	1.00	1.00
Tomakomai	0.48	1.00
Trieste	0.49	1.00
Tuticorin	0.76	0.91
Ulsan	0.60	1.00
Umm Qasr	0.49	0.86
Valencia	0.96	1.00
Vancouver (Canada)	0.89	0.93
Venice	0.58	1.00
Veracruz	0.56	0.90
Vladivostok	0.42	0.74
Vostochny	0.41	1.00
Wilhelmshaven	0.33	1.00
Yarimca	0.65	0.67
Yeosu	0.52	1.00
Yokohama	0.47	0.65
Zeebrugge	0.47	0.65

a. A variable returns to scale model was used to account for differences in throughput levels and economies of scale.
b. Interpret results for specific ports with caution as explained in section 7.

Source: Commission estimates using IHS Markit’s Port Characteristics data.

C. Review of international container port productivity literature

This appendix reviews the literature regarding the productivity and benchmarking of container ports.

Three approaches to benchmarking port performance are typically used:

- comparisons of performance metrics across ports
- creation of indexes based on port performance measures, characteristics or expert knowledge
- estimation production possibility frontiers (common in the academic literature[40]).

Each of these approaches are discussed below with a focus on Australian studies and results. Where relevant, the two main challenges associated with benchmarking are also discussed, these are:

- making like-for-like comparisons
- obtaining international data (particularly data that is comparable).

Comparisons of performance metrics

Benchmarking port performance by comparing productivity measures is typically conducted by government bodies and international organisations. This approach involves the comparison of a performance measure, such as gross crane rates, for a selection of ports in order to assess which port is most efficient, and where productivity gains can be achieved.

The Bureau of Infrastructure and Transport Research Economics (BITRE) and the Australian Competition and Consumer Commission (ACCC) have monitored and benchmarked the performance of Australian container ports for numerous years (BITRE since 1994 and the ACCC since 1998-99).

As discussed in appendix A, BITRE publishes *Waterline* (2021), which provides the latest available data on container terminal productivity for the five major Australian container ports. Throughput indicators, landside and quayside productivity indicators, and port interface costs are published. *Waterline* allows for productivity to be benchmarked domestically and over time.

BITRE conducted their own benchmarking study in 2009. Australia's five main container ports were compared with 29 overseas ports, most of which were selected because they are located in countries that are 'end of shipping line' trading countries. A number of measures were compared. The study found:

- net crane rates at Australian ports were below the median for overseas ports
- four Australian ports had vessel turnaround times that were longer than the median for overseas ports
- the duration of export and import procedures is faster in Australia than the median (as estimated by the World Bank) (BITRE 2009, p. 19).

[40] Another strand of the academic literature assesses the impact of reforms on port efficiency. For example, Cheon, Dowall and Song (2010) evaluated how port institutional reforms influenced efficiency gains between 1991 and 2004 for a sample of 98 ports. But this is not strictly a benchmarking technique.

The ACCC monitors and make an assessment of the productivity of Australian container ports. The ACCC (2021) recently compared net crane rates, elapsed labour rates and net ship rates of Australian container ports to those of New Zealand ports.[41] Tauranga and Auckland outperformed Australian ports on these measures. Data from UNCTAD were also used to benchmark median in-port time across countries. Median time in port for container ships visiting Australia was 1.4 days in 2020 — 'more than four times as long as Japan, more than double compared to China and 67 per cent greater than time that ships spent in Singapore or New Zealand' (p. 62). They cited industrial port action combined with port congestion and delays stemming from the COVID-19 pandemic as the reasons behind an increase of time in port from 1.2 to 1.4 days between 2019 and 2020 (p. 62). Overall, the ACCC conclude that 'although there has been productivity improvement at Australian ports … [they] are lagging behind [their] international counterparts' (p. 64).

The Commission has previously published two benchmarking studies of container ports, although these are now quite dated. The earlier study (1998) was broadest in scope, benchmarking different types of ports and operations within ports, while the follow-up study (2003) was focused on container stevedoring productivity.[42] Both relied on consultants to collect data and sampled overseas ports that had direct liner services to Australia, such as Singapore, Los Angeles, Hamburg and Auckland. Yet, most of these ports had a larger throughput than all the Australian ports combined making comparisons less informative (PC 1998, p. 16). Both reports compared static measures of performance, such as net and gross crane rates, lifts per employee and gross ship rates. Australian container stevedoring productivity was lower than the international ports included in the analysis, but productivity had improved between 1997 and 2002, such that there was an 'appreciable reduction in the overall productivity gap between Australian terminals and those at the overseas ports' (PC 2003, p. VII).

Turning to studies by international organisations, there are two notable organisations that have published reports on port performance — JOC Group and The United Nations Conference on Trade and Development (UNCTAD).

The JOC Group launched the Port Productivity Project, a precursor of the CPPI (JOC Group was acquired by IHS Global in 2014), which collected productivity information from 17 shipping lines representing over 70 per cent of global capacity (JOC Group 2013, p. 3). Gross berth productivity (that is, the number of container moves divided by hours at berth) was analysed for a global sample of ports (JOC Group 2013, 2014), stratified by the type of port (such as transhipment), ship size, location (continent) and by terminal (where possible). In 2013, the most productive ports were located in China (including Qingdao, Ningbo and Tianjin), the United Arab Emirates (Jebel Ali and Khor al Fakkan) and Japan (Yokohama). These ports moved between 106 and 130 containers per berth hour (JOC Group 2014, p. 17). The most efficient terminal was APM Terminals Yokohama which moved 163 containers per berth hour (JOC Group 2014, p. 19). Australian results were not reported.

The UNCTAD publishes an annual review of maritime transport, which includes a series of time-based performance measures at the country level. Using data from MarineTraffic, the study found that among the top 25 countries in terms of container port calls, only Australia, Indonesia, Vietnam and the United States recorded median port times (time spent within port limits) of more than one day (2020, p. 71). The report also used data from IHS Markit to analyse ship turnaround times (the time from when a ship reaches port limits (anchorage) to when it departs the berth). Australia took 34.6 hours on average to turn a ship around — half the time of the worst performing ports, but double the time of the best (2020, p. 85).

[41] New Zealand's Ministry of Transport collects the same stevedore performance measures as BIRTRE's Waterline making enabling comparisons.

[42] The two previous benchmarking studies were conducted by the Bureau of Industry Economics (BIE) and were published in 1993 and 1995.

Performance indexes

A number of indexes benchmark logistic systems internationally. Few focus on ports specifically, and fewer focus on efficiency. The Container Port Performance Index (CPPI) is most closely tied to efficiency, while others, such as the Liner Shipping Connectivity Index (LSCI) and Logistics Performance Indicators (LSI), are further removed. Each are discussed briefly below.

Container Port Performance Index (CPPI)

As discussed in the paper, in 2021, the World Bank (together with IHS Markit) released the inaugural CPPI, which benchmarked the efficiency of 351 international container ports. The index was created to compare operational performance across ports. It used time in port as a measure of performance and used two methods (a statistical and administrative approach) to derive two indices. The work attempts to compare similar ports by taking into account call and vessel size (see appendix D for a comprehensive review).

The data come from IHS Markit's Port Performance Program — a new collection and the most comprehensive port performance data available. Ten of the world's largest shipping carriers (accounting for 76 per cent of global fleet capacity) participate in the program and provide data on a number of performance measures such as gross crane rates, berth hours, anchorage times, call and vessel size. The data cover more than 1000 terminals in over 500 container ports (World Bank 2021, p. 41).

The top ranked container ports in the CPPI were Yokohama (Japan) and King Abdullah (Saudi Arabia). Australian ports were relatively inefficient and ranked below international best practice. The main Australian container ports, except for Brisbane, were found to be in the bottom 25 per cent of ports in the study. Brisbane was found to be in the bottom 50 per cent.

Liner Shipping Connectivity Index (LSCI)

The UNCTAD (2021c, p. 93) provides an indicator of a port's position within the liner shipping network (that is, the level of maritime connectivity for container shipping) using the Liner Shipping Connectivity Index (LSCI). The index was first created in 2004 at a country level, and in 2018 changed to port level, drawing on data from a number of sources (such as MDS Transmodal and Containerisation International Online). The World Bank (2021, p. 30) noted that 'while a port's position is in part determined by the port's performance, the LSCI does not directly measure it', but it is 'highly correlated with performance and low trade costs' (p. 36).

The index is generated from data on container ship deployment and has six components: the number of companies (shipping lines) that provide services; the number of scheduled services; the number of ships that call per month; the total annualised deployed container carrying capacity; ship sizes; and the number of countries that can be reached without the need for transhipment.

At a country and port level, the performance of Australia has improved since 2006, but still lags behind international ports (UNCTAD 2021a, 2021b). Melbourne is the top ranked Australian port, followed by Sydney, Brisbane, Fremantle and Adelaide. This is perhaps unsurprising given that Melbourne is the largest port and therefore likely the most connected. Also, there is a high correlation between port throughput (TEUs) and LSCI scores (UNCTAD 2020, p. 81). The export-oriented economies and ports of China, Hong Kong, South Korea and Singapore dominate the rankings.

Logistics Performance Indicators (LPI)

The Logistics Performance Indicators (LPI) are produced by the World Bank. The LPI is the weighted average of a country's performance scores on six key dimensions of logistics systems. The data come from a survey of logistics professionals at multinational freight forwarders and the main express carriers, for example, the 2018 LPI was based in a survey of 869 respondents at international logistics companies in 108 countries (Arvis et al. 2018, p. 63).

In the 2018 LPI, Australia ranked 18th of 160 countries, moving up one position since 2016 (Arvis et al. 2018, p. 45). Australia is performing at 90 per cent of the top performer, indicating that there are efficiency gains to be made, especially in the area of international shipping (Arvis et al. 2018, p. x). The six dimensions are (including Australia's ranking in 2018):

- customs: efficiency of the customs clearance process (that is, speed, simplicity and predictability of formalities) by border control agencies, including customs (Australia ranked 7th)
- infrastructure: quality of trade and transport related infrastructure (such as, ports, railroads, roads, information technology) (16th)
- international shipments: ease of arranging competitively priced shipments (40th)
- services quality: competence and quality of logistics services (such as, transport operators, customs brokers) (21st)
- tracking and tracing: ability to track and trace consignments (20th)
- timeliness: shipments in reaching destination within the scheduled or expected delivery time (21st).

Estimating production possibility frontiers

The academic literature analyses the technical efficiency (the effectiveness of converting inputs to outputs) of ports by estimating production possibility frontiers. The estimated frontier, which is identified by the best performing ports, represents the efficient standard against which other ports can be compared. These models have also been used in other sectors including education, health care, airports, electricity and other transport systems.

Two main methods are used for frontier analysis: data envelopment analysis (DEA, non-parametric model) and stochastic frontier analysis (SFA, parametric model). These models require data on the inputs (land, labour and capital) and outputs of container ports. DEA is a deterministic means of constructing a frontier such that the distribution of sample points is observed and a 'kinked' line is constructed around the outside, 'enveloping' the points to draw the frontier. SFA is a regression technique which tries to take account of outliers which either are atypical or appear to be exceptional performers as a result of data measurement errors. There is no consensus on which method is best; both have advantages and disadvantages but there is evidence to suggest the two approaches produce similar results and conclusions (Wang and Cullinane 2015, p. 256).

There are numerous applications of both methods to container ports, but DEA tends to be more commonly used. Table B.1 summarises over 50 studies of container port efficiency, including the number of ports studied, the method and the input variables and output variables used in the model.

A number of observations are made from the Commission's review, in combination with a number of other recent literature reviews (Gil-Ropero, Cerban and Turias 2015; Kutin, Nguyen and Vallée 2017; Mustafa, Khan and Mustafa 2021; Odeck and Bråthen 2012; Odeck and Schøyen 2020).

- Most studies used DEA (likely because SFA requires larger samples and assumptions on the functional form adopted).
- For a small sample with homogenous ports, DEA-CCR (constant returns to scale) is used, but for a larger sample with heterogenous ports, both DEA-CCR and DEA-BCC (variable returns to scale) is used (Kutin, Nguyen and Vallée 2017, p. 68).
- Data are usually collected manually (for example, from port authorities, terminal operators, industry reports, or the Containerization International Yearbooks).

- Samples are usually concentrated in a specific country or geographic region, with few studies of ports globally. This could be due to data availability or an attempt to benchmark comparable ports.
- Sample sizes usually range from 5 to 70 ports, few have larger samples.
- The output variable most commonly used is annual container throughput (TEUs). Less commonly used output variables include ship calls or ship rates.
- The inputs most commonly used are terminal area, quay length, number of container berths, and number of quay cranes.
  - Few studies account for labour inputs because obtaining the requisite data is difficult (sometimes because it is commercially confidential). Some studies use poor proxies such as the number of port authority employees.
- Few studies try to identify the determinants of port efficiency.

Australian container port findings

A handful of papers include Australian ports in a frontier analysis. All followed a DEA approach.

- Tongzon (2001) applied a DEA (constant returns to scale and additive) to analyse a sample of four Australian (excl. Adelaide) and 12 international container ports using data for 1996. The study found that Melbourne, Rotterdam, Yokohama and Osaka were inefficient, mainly due to the enormous slack (excess capacity) in their container berths, terminal area and labour inputs.
- Bray et al. (2014) applied a fuzzy DEA (that is, a variant on the standard DEA model) to analyse a sample of four Australian and 12 international container ports using data from 1996. The study found that Melbourne, Sydney, Hamburg and Rotterdam were inefficient.
- Hui et al. (2019) applied a DEA (constant and variable returns to scale) to analyse a sample of Australian, Indonesian and Chinese container ports for data for 2015. The study found that Melbourne, Sydney and Fremantle were all technically efficient, as was the port of Shanghai. The Indonesian ports were not.

These studies relied on small sample sizes which can bias DEA results towards identifying more ports as efficient when they actually are not. Further, ports that are of a different type (hub or feeder ports) and that are much larger than the Australian ports are included — such as, Shanghai, Singapore and Rotterdam — which may limit comparability to Australian ports.

Two studies overcome the small sample bias. One also accounts for differences in port size.

- Merk and Dang (2012, p. 35) applied a DEA (constant, variable and non-increasing returns to scale) to analyse a sample of 126 container ports using data for 2011. Three Australian ports were included — Melbourne, Sydney and Brisbane — none of which were found to be technically efficient. But Brisbane performed the best with a ranking of 35 (and DEA-BCC score of 0.6), Melbourne was ranked 87 (0.16), and Sydney was ranked 121 (0.01).
  - This study also applied DEA to other types of ports, including oil terminals, bulk coal, bulk iron ore and grain terminals. Australian ports were among the most efficient in handling bulk coal (Hay Point, Newcastle and Gladstone) and bulk iron ore (Port Walcott and Gladstone).
- Ghiara and Tei (2021) applied a DEA (constant and variable returns to scale) to analyse a sample of 213 container ports, including seven Australian ports (the main five and two Tasmanian ports), using data from 2017. The authors stratified their DEA by the size of the port's throughput (small, medium and large) recognising that economies of scale are likely present and that stratification enables fairer comparisons to be made. They found the Tasmanian ports of Burnie and Devonport were among the most efficient

performers for their small size. The other Australian ports considered were in the 2nd quartile for their respective sizes.

In contrast to the World Bank's CPPI rankings, these studies show that Australian container ports are not among the most inefficient ports internationally. Yet, most studies find Brisbane to be relatively more efficient than the other Australian ports. It is also worth noting that:

- the method and therefore underlying measures of efficiency differ between the typical DEA study and the World Bank's CPPI methodology. The typical DEA focuses on how well inputs are converted into port throughput, while the CPPI focuses on the time it takes to turn over a ship (a measure of port call hours)
- trying to compare like-for-like ports is handled differently. The CPPI analyses performance within call and ship size range, while some DEA studies stratify results by port size.

Overall, these studies indicate that there is scope for efficiency improvements in Australian ports.

Table C.1 – Literature review of DEA and SFA studies of container ports

Author (Year)	Region and sample	Year(s) studied	Model	Inputs	Outputs
Almawsheki and Shah (2015)	19 ports, Middle East	2012	DEA-CRR	Berth area; quay length; quay crane; handling equipment	Container throughput
Barros (2005)	10 ports, Portugal	1990-2000	SFA	Operational costs; total salary / number of employees; earnings / book value of premises; number of ships	Total cargo
Bergantino, Musso, and Porcelli (2013)	30 ports, Europe	1995-2009	Three stage DEA-BCC; SFA	Berth length; No. of terminals; port area; handling equipment	Container throughput
Bichou (2012)	420 container terminals	2004-2010	DEA-CCR; DEA-BCC; Panel data	Terminal area; Max draft; Quay length Quay crane Index; Yard-stacking index Gates	Container throughput
Bray et al. (2014)	16 ports (4 Australian)	1996	Fuzzy DEA	Number of cranes; Container berths; Number of tugs; Terminal area; Delay time; Number of port authority employees	Container throughput; Shiprate; Shipcalls; Crane; productivity
Coto-Millan, Banos-Pino, Rodriguez-Alvarez (2000)	27 ports, Spain	1985-1989	SFA	Employee costs, depreciation and intermediate consumption	Throughput
Cullinane and Song (2003)	5 ports, UK and Korea	1996	SFA	Remuneration of directors or executives; total wages; book value of fixed assets; book value of mobile assets	Container throughput
Cullinane and Wang (2007)	57 container terminals	2001	DEA-CCR; DEA-BCC;	Terminal Area; Quay cranes; Yard cranes; Straddle Carriers	Container throughput

Author (Year)	Region and sample	Year(s) studied	Model	Inputs	Outputs
Cullinane et al. (2002)	15 ports, Asia	1989-1999	SFA	Quay length; terminal area; No. container handling equipment	Container throughput
Cullinane, Song, Ji, and Wang (2004)	25 container terminals, global	1992-1999	Window, CCR and BCC	Berth length; terminal area; no. of berth cranes; no. of yard cranes; no. straddle carriers	Container throughput
Cullinane, Wang, Song, & Ji (2006)	30 container ports	2001	DEA-CCR; DEA-BCC	Terminal length; Terminal area; Quay cranes Yard gantry cranes; Straddle carriers	Container throughput
Dan et al. (2013)	19 container ports, China	2010	Three stage (Input Oriented DEA-BCC)	Berth length; Handling equipment & staff quantity	Container throughput
Demirel et al. (2012)	16 container ports, Turkey, Greece, Egypt, Romania, Russia, Israel	2006-2008	DEA-CCR; DEA-BCC	Quay length; Terminal area; Quay cranes; Yard equipment; Maximum draft	Container throughput
Dong et al. (2019)	10 ports, Maritime Silk Road	2017	DEA-CCR, DEA-BCC	No of berths; berth length; no. of quay cranes	Container throughput
Ghiara and Tei (2021)	213 ports in 30 countries (some Australian ports included)	2017	DEA-CCR DEA-BCC	Berth length; average depth; no. of berths	Container throughput
Gil-Ropero et al. (2013)	13 container ports, Spain	2008-2011	DEA-CCR, DEA-BCC	Number of gantry cranes; Terminal area; Berth length	Container throughput
Gil-Ropero et al. (2019)	16 container ports, Spain and Portugal	2008-2014	DEA-CCR, DEA-BCC, DEA bootstrapped	total quay length; the terminal area; the number of quayside cranes; the number of yard gantry cranes; the number of straddle carriers	Ship calls; Container throughput
Hai-bo and He-zhong (2009)	13 ports, China	2004-2006	SFA	Net permanent asset; Total employees	Main business revenue
Hlali (2018)	26 ports, global	2015	DEA; SFA	Quay length; draught; terminal area; storage capacity	Container throughput
Hui et al (2019)	3 Australian ports; 2 Indonesian ports; 1 Chinese port	2015	DEA-CCR; DEA-BCC	Land size; length of berths; no. of berths; no. of cranes; operating expenses; net assets; number of employees	Container throughput; bulk throughput; crane rate; ship rate
Hung et al. (2010)	31 container ports, Asia-Pacific	2003	DEA-CCR; DEA-BCC; DEA	Terminal area; STS container gantry cranes (No); Berths	Container throughput

Author (Year)	Region and sample	Year(s) studied	Model	Inputs	Outputs
			with bootstrap method	(No); Total quay length	
Jiang and Li (2009)	12 container ports, Asia	2007	DEA-CCR; DEA-BCC.	Import/Export by customs; GDP by regions; Berth Length; Crane number	Container throughput
Kamble et al. (2010)	12 ports, India	2020	Output oriented DEA-BCC	Storage yards; No. of berths & cargo handling equipment	Avg. total turnaround time; Avg. output/ship berth day
Konstantinidis and Pelagidis (2018)	6 ports, Africa	2006-2012	DEA; SFA	Quay length; terminal area; no. quay cranes; no. gantry cranes; no. reach stackers	Container throughput
Kutin et al. (2017)	50 ASEAN container ports and terminals	2014	DEA-CCR; DEA-BCC.	Max depth at berth; yard size; qual length; no. of cranes; no. of yard cranes; no. of fork lifts; no. of trucks	Container throughput
Li et al. (2013)	42 ports, China	unknown	DEA; SFA	Terminal length Handling equipment (bridge, mobile and beam cranes) Number of employees	Container throughput
Li, Kyu-seok, Ki-Chan, and Young-Mo (2015)	16 ports, North East Asia	unknown	DEA-CCR, DEA-BCC	No. of berths; berth length; depth; no. of cranes; terminal area	Container throughput
Lim, Bae and Lee (2011)	26 container terminals, Asia	2004	Additive non-oriented DEA RAM	Quay length; Total area; Gantry Cranes	Container throughput
Lozano, Villa and Canca (2011)	28 ports, Spain	2006	Centralised DEA using a non-radial Russell measure of technical efficiency.	Land and stacking area; Total quay length Total number of cranes; Number of tugs	Total port traffic; Container Throughput; Ship calls
Medda and Liu (2013)	165 world container terminals, global	2006	SFA	Berth depth; quay length; yard space; number of gantry cranes spacing; terminal type (container versus multipurpose); operation type (global versus local)	Container throughput
Merk and Dang (2012)	126 ports (Brisbane, Melbourne, Sydney included), global	2011	DEA-CCR, DEA-BCC, bootstrapped, non-increasing returns to scale	Quay length; terminal area; refeer points; no. of quay cranes; no. of yard cranes	Container throughput (both DWT and TEU)

Author (Year)	Region and sample	Year(s) studied	Model	Inputs	Outputs
Merkel (2018)	77 ports, Europe	2002-2012	SFA	Terminal area; berth length; No. quay cranes; No. reach stackers; draught	Container throughput
Munim et al. (2021)	38 container terminals, 17 ports, Asia	2009	DEA-CCR; DEA-BCC; FDH	No. of berths; berth length; depth; terminal area; no. of yard cranes; no. of quay cranes	Container throughput
Mustafa et al (2021)	30 ports, East and South Asia and the Middle East	2018	DEA-CCR; DEA-BCC	No. of cranes; berth length; no. of berths; draught	Container throughput
Nguyen et al. (2016)	43 ports, Vietnam	2013	Bootstrap DEA; SFA	Berth length; Terminal areas; Warehouse capacity; Cargo handling equipment	Container throughput
Odeck and Schøyen (2020)	24 ports, Nordic and UK	2002–2014	SFA	Berth length; terminal area; No. cargo handling machines	Container throughput
Rajasekar and Deo (2018)	8 ports, India	1993-2011	DEA Additive; DEA-CCR; DEA-BCC	No. of berths; berth length; no. of equipment; no. of employees	Total traffic; Container throughput
Rios and Maçada (2006)	15 Brazilian; 6 Argentinean; 2 Uruguayan container terminals	2002-2004	DEA-BCC	No. of cranes; no. of berths; no. of employees; terminal area; amount of yard equipment	Container throughput; ship rate
Serebrisky et al. (2016)	63 ports, Latin America and the Caribbean	2009	DEA-CCR DEA-BCC	Quay length; Terminal area; Mobile cranes with more than 14T. capacity; STS gantry cranes	Container throughput
Seth and Feng (2020)	15 ports, United States	2001-2015	DEA Window analysis	Cost of port security measures; Cost of container infrastructure; Dredging cost; Berth length; Number of cranes; Container terminal area	Net income; container throughput
Sharma and Yu (2010)	70 container terminals, global	unknown	DT based context-dependent DEA	Quay cranes; Transfer cranes; Straddle carriers; Reach stackers; Quay length Terminal area	Container throughput
Suárez-Alemán et al. (2016)	203 ports, in 70 developing countries	2000-2010	SFA	Terminal area; No. of mobile cranes; No. of gantry cranes; Berth length; Exogenous variables	Container throughput

Author (Year)	Region and sample	Year(s) studied	Model	Inputs	Outputs
Tongzon (2001)	4 Australian and 12 international ports	1996	DEA-CCR; Additive DEA.	Number of cranes; Number of container berths Number of tugs; Terminal Area; Delay time; Labour (units)	Container throughput Number of ship calls
Tongzon and Heng (2005)	25 ports	1999	SFA	Quay length; terminal area; no. quay cranes; port size; private participation	Container throughput
Trujillo and Tovar (2007)	22 ports, Europe	2002	SFA	Average number of persons employed by the port authority; port land; containerization rate	Throughput
Wang and Cullinane (2015)	104 ports, Europe	2003	DEA-CCR, DEA-BCC	Terminal length; terminal area; equipment cost	Container throughput
Wanke (2013)	27 ports, Brazil	2011	Network-DEA centralized efficiency	Number of berths; Warehousing area Yard area; Container frequency (shipments)	Container throughput
Wilmsmeier et al. (2013)	40 ports, Central and South America	2005-2011	Malmquist index	Terminal area; Quay crane capacity equivalent; Number of employees	Container throughput
Wilmsmeier, Tovar, and Sanchez (2013)	10 ports, Latin America, Caribbean and Spain	2005-2011	DEA	Berth area, quay crane; labour capacity	Container throughput
Wu and Goh (2010)	21 ports, global	2005	DEA-CCR; DEA-BCC; DEA Windows Analysis	Terminal area; Total quay length; No. of pieces of equipment	Container throughput
Zarbi, Shin, and Shin (2019)	5 ports, Iran	2008-2017	DEA Windows	Quay wall length; no. of berths; no. of gantry cranes; yard space	Container throughput
Zheng and Park (2016)	20 ports, Korea and China	2014	DEA-CCR, DEA-BCC	Berth length; Yard area; No. of quay cranes; No. of yard cranes	Container throughput

Notes: DEA-CCR = constant returns to scale; DEA-BCC = variable returns to scale.

D. The World Bank's Container Port Performance Index

This appendix summarises the World Bank and IHS Markit's (2021) *The Container Port Performance Index 2020: A comparable assessment of container port performance* study, covering:

- the motivation for the study
- the data and analysis sample
- how port productivity is conceptualised, and the two types of methodologies used
- the CPPI results, with a focus on Australia's performance.

Throughout the appendix, caveats on the study are mentioned as well as instances where the World Bank intend to make improvements upon the 2020 methodology in future iterations of the CPPI . While there is a focus on the caveats and areas for improvement, the Commission notes that the CPPI is an admirable attempt at aggregating a wealth of data into an index that has encouraged conversations about the efficiency of container ports, which are critical the global economy.

Motivation for the CPPI

Efficient container ports matter because:

> … over the medium to longer term, an inefficient port will result in slower economic growth, lower employment, and higher costs for importers and exporters. (World Bank 2021, p. 8)

Data in the area of container port efficiency has been lacking:

> … the quality, consistency, and availability of data, the definitions employed, and the capacity and willingness of the organizations to collect and transmit data to a collating body, have all precluded the development of a comparable measure (or measures) to assess performance across ports, and time. (World Bank 2021, p. 8)

The 2020 index is the first time a *global* benchmarking exercise has been undertaken for container ports:

> … CPPI is intended to identify gaps and opportunities for improvement and hopefully stimulate a dialogue among key stakeholders and move this essential agenda forward. (World Bank 2021, p. 9)

Data: IHS Markit's Port Performance Program

The data used to compile the CPPI 2020 are gathered from the IHS Markit's Port Performance Program (see appendix A for more details).

Sample

This first iteration of CPPI utilised data for July 2019 to June 2020 and included ports that had a minimum of 10 valid port calls (and hours data) within the two six-month periods covered. A total of 351 ports out of 502 ports in the IHS Markit database are included in the 2020 CPPI (covering 765 terminals and 2877 vessels). This covered 67 798 distinct port calls, representing more than 50 per cent of the world's total container ship port calls. Future iterations of the CPPI will look to:

- include data for additional, often smaller, ports that have significant issues with automatic identification systems (AIS, maritime communications device aiding in navigation) coverage (World Bank 2021, p. 51)
- offer some comparative analysis on year-to-year changes (World Bank 2021, p. 69).

Caveats

- A matching process is undertaken to verify the call data provided by shipping lines with the data collected from AIS systems. This process successfully verifies around 90 per cent of port calls. This means that data for 10 per cent of port calls failed validation. The main reason that some ports were excluded is because they used satellite AIS systems, which are less reliable than comparable land-based systems, meaning that port calls could not be verified.
- Some ports did not meet the inclusion criteria for the construction of the CPPI (that is, they had a lack of port call data: fewer than 10 valid port calls in previous six months with data on port hours), these were typically smaller ports.
- Overall, 151 ports were excluded from the CPPI. As a result, the performance results are skewed towards larger ports and towards the performance of large container ships because the data was collected from larger container ship operators. To overcome this limitation, data for many sister or subsidiary companies that specialize in intraregional or feeder operations for program participants were also included.

Methodology

Conceptualising port performance

Many factors affect the efficiency of a port:

> … the efficiency of the port itself, the availability of sufficient draught, quay, and dock facilities, the quality of the connections to road and rail services, the competitiveness of those services, and the efficacy of the procedures employed by the public agencies involved in container clearance. (World Bank 2021, p. 28)

The focus of the CPPI 'is **purely on quayside performance** (including marine operations) to be reflective of the experience of a ship operator, the port's main customer' (World Bank 2021, p. 31).

Shipping line (container) services are generally highly structured, service rotations. These services are typically set up with weekly departure frequencies, a fixed sequence of port calls, and standard day and time-specific berthing windows. This structure should result in high levels of reliability and predictability and enable shippers to make long-term supply decisions and enable ports/terminals to schedule and balance their resources to meet expected demand.[43]

[43] As discussed in the body of the paper, the structured nature of these services has been adversely affected by COVID-19 pandemic.

Shorter port times can allow ship operators to reduce vessel speed between port calls, thereby conserving fuel, reducing emissions, and lowering costs in the process (World Bank 2021, p. 44).

Conversely, any increase in time in port or anchorage can lead to delays to shipments and disruption to supply chains, higher sailing speeds, increased fuel consumption, emissions and costs, or the omission of a port or ports from a standard rotation. Time delays may result in higher costs (for shippers, shipping liners, container terminal operators and other participants in maritime supply chains).

Recognising the importance of **time** for stakeholders, the CPPI measured port performance based upon the total amount of time that ships spend in port (World Bank 2021, p. 44).

The key performance variable in the CPPI is **total port hours per ship call**, defined as the elapsed time between when a ship reaches a port (either port limits, pilot station or anchorage zone) and its departure from the berth having completed its cargo exchange. This time consists of two components:

- the time between when a ship reaches a port and when the ship is securely berthed (referred to as 'all lines fast')
- the on-berth time.

Time taken to leave the port is excluded, because departure delays (such as pilot or tug availability, readiness of the mooring gang, channel access and water depths, and ship readiness) will be incurred while the ship is still berthed.

Caveats

- After cargo operations, ships may not leave the berth immediately. The study claimed most of these delays are generally not inefficiencies at the port, with the obvious exception of waiting for clearance to be authorised. Instead, ships may not be operationally ready, need repairs or fuelling. The nature of the timing data makes it impossible to isolate these different effects. Instead, the study 'presumes the percentage of ships idling alongside after completion of cargo operations for reasons unrelated to port performance is modest, and thus continued inclusion will have no significant effect on the CPPI results' (World Bank 2021, p. 46).
- In consultations, DP World commented that the World Bank study only focuses on one key measure of performance (that is, it does not consider the time taken to move a container out of the terminal and to its destination, which is typically longer than port operations and critical for the supply chain). DP World claimed that Australia would rank higher if this was considered, since a container sits on dock for 2.5 days, a lower time than many other ports. The World Bank do not have data that enables them to take a more holistic approach.
- Smaller ships (<1500 TEUs) tend to wait longer to berth, so ports with more smaller ships may look relatively more inefficient (unless the method accounts for this). The study claimed that these types of calls accounted for less than 10 per cent of all ship calls and this issues therefore has a minimum impact on the CPPI (World Bank 2021, p. 48).

Method

Key data observations that shape the analysis

- Port time is dominated by container handling operations (averaging 75 per cent of total port time) (World Bank 2021, p. 52). The ratio of time spent on handling operations generally increases with ship size and call size (the number of containers that need to be moved). This is partially offset by larger ships spending less time waiting in port, as they 'potentially enjoy a slightly higher priority and assignment of resources' (p. 52).
- There is a high correlation (60 per cent) between call size and crane intensity, meaning that more cranes are typically deployed to handle larger call sizes (World Bank 2021, p. 53).

- Average call size increases as ship size increases, but not proportionately with ship size (World Bank 2021, p. 54).
- Average global gross crane rates differ by ship size. Ships under 5000 TEUs generally have lower gross crane rates, ranging from 22-23 moves per hour compared to ships larger than 5000 TEUs, which have crane rate of around 25 moves per hour (World Bank 2021, p. 55).
- Crane intensity (that is, the average number of cranes deployed to a ship's berth call) differs by call size, and therefore has a major impact on handling time and, by extension, total port time (World Bank 2021, p. 56).

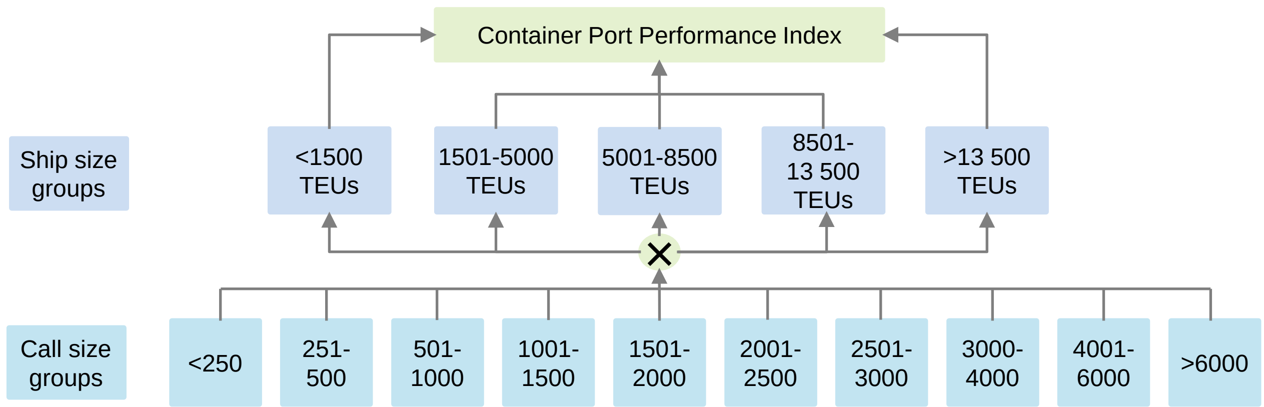
These observations suggested that the CPPI (especially the operating hours productivity component) should take into account both ship size and call size. Ports that deploy more cranes would appear relatively more efficient and, therefore, rank higher than ports that handled smaller loads and could deploy fewer cranes, if ship and call size were not accounted for.

Ship and call sizes used by the World Bank are presented in figure D.1.

- Call size groups need to be such that they neutralise the impact of call size and crane intensity on productivity, but do not to spread the data too thinly (too few observations in each category cell). The CPPI evaluated 10 call size groups.
- Ship size groups (although less important once call size is taken into account) are included because larger ships use more fuel and thus present an opportunity to save fuel and reduce emissions. Ship size could also be important for routes serviced by a large vessel stopping at multiple ports because the call size could be very different from the ship size (this could be the case for Australian ports). The CPPI evaluated 5 ship size groups ranging from feeders, intraregional, intermediate, Neo-Panamax and ultra-large container carriers.

Figure D.1 – Structure of the CPPI

Call size and ship size categories selected



The CPPI considers 50 (5 by 10) potential ship and call size categories. Some of these categories are omitted because of insufficient data (for example, it is impossible for a ship with a capacity of 1500 TEUs has a call size greater than 4000 moves). Seven ship-call size categories are removed, which results in 43 ship-call size categories in the analysis.

Constructing the analysis data

Data for each ship size group were extracted from the full port call dataset, and aggregated to calculate average port hours within each call size group for each port. There is an inherent limitation in this approach in that, while there is ample data for each category for larger ports (the top 100), this is not always the case for smaller ports, particularly those with a few hundred port calls. The study stated:

> If these unpopulated categories are ignored, the performance appraisal would be undertaken on different quantities of categories, which is likely to unduly disadvantage smaller ports that might well be quite efficient despite their modest size and throughput. (World Bank 2021, p. 60)

As a result, two **imputation** methods were used to impute missing data (one for each of the two methods used in deriving the index).

- The **administrative** approach uses an imputation method that examines whether a port performed better or worse than the average port for a call size category, and then assumes that the port would have also performed better or worse in the adjacent missing call size category and then imputes a value.
  - The risk is that this approach assumes that poor/good performance within one call size range (for a given ship size), cascades across other call sizes. It also assumes a port can add cranes to larger call size groups, which may not be the case.
- The **statistical** approach uses an expectation–maximization (EM) algorithm to provide a maximum likelihood estimator for each missing value. This relies on two assumptions:
  - missing values are random, that is, not due to some bias in the sample selection process
  - all variables under consideration are normally distributed.

  The study claimed that these are both realistic assumptions. (In addition, to run the factor analysis used in this approach (explained below), complete data is needed for each of the 43 distinct ship-call categories, meaning missing data had to be imputed. Without imputation many ports would be dropped from the sample.)

Importantly, data is not imputed in all cases. Not all ports are included within each ship size category. For example, if it is impossible for a small port to accommodate a large ship (or has very few calls from large or small ships) then that port is excluded from the ship size category (table D.1). In the Australian context:

- all ports are *excluded* from the largest ship category (more than 13 500 TEUs)
- Melbourne, Adelaide and Fremantle are *excluded* from the smallest ship category (less than 1500 TEUs).

Table D.1 – Quantity of ports includes per ship size group

Ship size range (TEUs)	Number of ports included	Base call size
<1500	219	251-500
1500-5000	331	501-1000
5001-8500	213	1001-1500
8501-13 500	162	1501-2000
>13 500	99	2001-2500

Constructing the index

As noted above, the study used two approaches to constructing the CPPI:

- administrative approach
- statistical approach.

The study claimed that 'neither methodology is better than the other; rather, the two different approaches complement each other' (World Bank 2021, p. 67) and this is why both methods were used.

Both approaches go some way to comparing like-for-like by comparing port performance within ship and call size categories. But aggregation of these comparisons to a port-wide measure of efficiency does risk the introduction of bias (for example, by giving larger weightings to the performance of handling large ships in the aggregation process).

Administrative approach

> … the administrative approach reflects … an aggregate of the performance of the port, weighted relative to the average, across call and vessel size. Accordingly, the score can be negative, where a port compares poorly to the average in one call size and vessel size category, particularly if they do not have an offsetting positive score(s) in other cell(s). (World Bank 2021, p. 12)

The administrative approach is described in steps below.

- Step 1: sum arrival and berth hours to form total port hours (with a weighting of 1.0 each).
- Step 2: within each ship-call size category: compare a port's average port hours with the group average to construct a ratio of performance (for example, drawing on the example presented in table D.2 below, 22.71/19.72 = 1.152). This is multiplied by the call size group weight (the share of all port calls in the ship size category that were in that call size category). A higher result indicates better productivity.

Table D.2 – Administrative example

Port	Port hours	Score	Call size group weight	Result
Example port	19.72	1.152	0.232	0.2672
Group average	22.71			

- Step 3: within ship size category, sum the results across all call size categories.
  - Caveat: the imputation method might bias a port's performance if it only had data for limited call size ranges. For example, if the performance in a few call size groups was worse than the average for all ports within the ship size group, this would be prorated to all call size groups. The study argued that the alternative of a zero score would not necessarily result in a better outcome.
- Step 4: aggregate across all ship sizes to determine a final score. This a sum of the weighted average of the scores for each ship size category, weighted by a fuel consumption index (where larger ships have higher weights). The premise underlying use of the fuel consumption index is that if a large ship spends longer in port, it will have a larger negative impact (costs, fuel consumption, environment etc.), therefore performance in turning around a larger ship is recognised as being of greater significance than performance in turning around a smaller ship. Similarly put, larger ships present a greater potential opportunity to save fuel and reduce emissions.

- Ports that could not handle larger ships receive a zero (or a missing) score for that ship size group (as indicated in table D.1 above). The study noted:

  > The omission of scores within some ship size groups would only be an issue if attempting to compare the performance of major mainline ports with those of far smaller ports; however, this comparison is neither objective nor valuable. (World Bank 2021, p. 64)

  Further, assigning a zero score or missing is essentially the equivalent of assigning that port the average score for that ship size group. Therefore, it should not bias rankings.
- Caveat: if fuel consumption index values are adjusted so that larger ship size groups have lower indices than smaller ones, the overall ranking results can change **radically**. Further, after applying this index, the ranking now incorporates some measure of environmental externalities, rather than focusing on port efficiency in handling ships. It begs the question, how would the rankings change with equal weights?

• Step 5: the scores are ranked in descending order, where **positive** scores are indicative of a more efficient port.

Statistical approach

The statistical approach uses factor analysis to ascertain the performance of ports.

Factor analysis (FA) can:

• summarise data in large datasets efficiently
• ascertain the impact of a series of measured variables (which contain information about the efficiency of a port, in this case time-based measures) on an unseen latent variable (efficiency), which cannot be measured directly with a single variable. The actual values of these time-based measures are determined by a small number of unobserved factors, such as the availability and quality of the infrastructure, the layout of the port, the expertise of the employees, the available depth in the channel and at the berth, and so on. The latent variable, efficiency, is considered to be a function of each of the measured variables (the time-based measures) and an error term for each.

The steps involved are:

• Step 1: conduct a factor analysis for the five ship size categories individually (that is, run a factor analysis using the port time data for all the call sizes within a ship size category).
• Step 2: identify how many latent factors should be included (typically factors with an eigen value greater than one).[44] The study identifies three factors that contribute to efficiency (and cover 80 per cent of the total variance), loosely speaking these are related to inefficiencies in handling small, medium and large calls.
• Step 3: the factor score is calculated and standardised (with mean 0, standard deviation 1), such that a **negative** score is indicative of a port being more efficient than the average port.
• Step 4: create a weighted average score (a weighted average sum of the factor scores for each ship size category), where the weights are the same as those used under the administrative approach — that is, the fuel consumption index.

  - Some ports will not have a score for some ship sizes (for example, greater than 13 500 TEUs for Australia's container ports), and in these cases the assumed imputation is zero. By construction, zero is always the group average score of observed ports in the factor analysis, thus assigning zero to ship size categories where ports that do not have a score does not penalise those ports unfairly. However,

[44] Rotation of the factors also takes place to allow for ease of interpretation. The study employs the common varimax rotation.

the application of the fuel consumption index which gives higher weights to larger ships means that ports that efficiently handle larger ships will receive higher scores than those that efficiently handle smaller ships, all else equal.

The key difference between the approaches: Under the factor analysis (or statistical) approach, the scores are not calculated for each call size range. Instead, the whole dataset is used to simultaneously obtain latent factors. This means that the statistical approach factors in all correlations among hours for various call size bands but does not consider the fact that some observations might be more reliable than others as there are more port calls data underlying the observation (under the administrative approach the score for a ship-call size is multiplied by the share of calls in the category to apply more weight to call-sizes with more underlying port calls data). The study stated that:

> This implies the results, and potentially the ranking, for some of the ports could be distorted in the presence of large outliers. (World Bank 2021, p. 67)

Interestingly, neither of the approaches use individual port call data, and instead rely on a measure of average port hours (in each ship-call size category for each port). For the factor analysis, port call data could have been used, but presumably the shipping lines did not give permission for their port call data to be used or there was too much data to manipulate.

CPPI results

This section presents the results for the CPPI, highlighting the performance of Australian container ports.

Overall results

There is a high degree of correlation between the ranking of ports using the administrative and statistical approach (figure D.2). The World Bank noted that:

> Just under 18 percent of all ports (61 ports) are ranked within three places or less from themselves in the two rankings. Approximately 40 percent (137 ports) are ranked with ten places or less of themselves in the respective rankings, while 80 percent (282 ports) fall within 10 percent of their respective rankings in the two indices. (World Bank 2021, p. 13)

However, there are some exceptions such as Jebel Ali which is ranked 59th under the administrative approach but 323rd under the statistical approach or Dunkirk which is ranked 305th under the administrative approach but 118th under the statistical approach (these lie further off the 45 degree line in figure D.2). The World Bank noted:

> … the approach taken in the CPPI 2020 has been not to try and explain every discrepancy, but rather to make the methodology and assumptions explicit and let the data speak. (World Bank 2021, p. 26)

In future revisions of the CPPI, the World Bank will ‘seek to investigate and explain divergences between the two approaches, while also gaining a further understanding of key determinants or influences on container port performance’ (World Bank 2021, p. 26).

The CPPI includes the five main Australian container ports:

- Port of Melbourne
- Port Botany (Sydney)
- Port of Brisbane

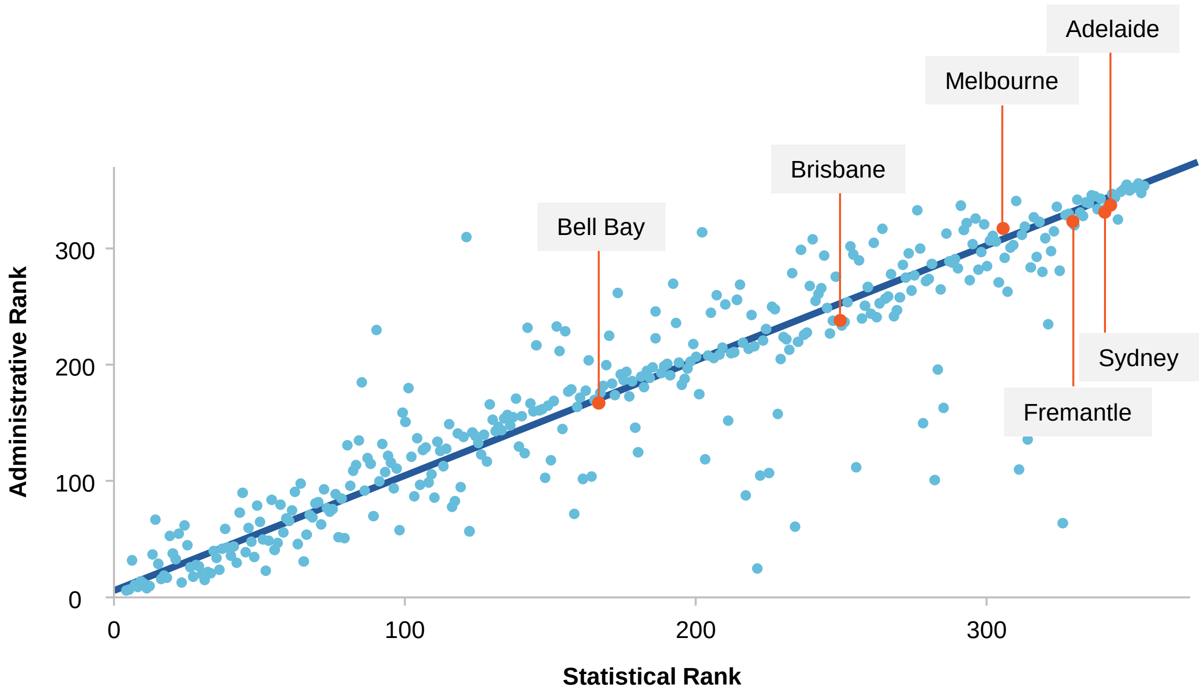
- Port of Fremantle
- Port Adelaide (Flinders).

The port of Bell Bay in Tasmania was also included in the CPPI. Bell Bay can be regarded as a domestic port rather than an international port because it mostly receives containers from Melbourne, and it has a small annual throughput (26 000 TEUs) compared with the other ports. For these reasons, Bell Bay port is not the focus of this analysis, although it is ranked higher in efficiency than the other Australian container port.

The Australian ports rank similar under both approaches (figure D.2). For this reason, the remainder of the results are presented for the statistical approach. This approach assigns each port a score which ranges from -6 to 8.4, where, as noted above, negative numbers indicative of greater efficiency. For ease of interpretation, the scores have been converted to an index of efficiency, with the most efficient port given a score of 100 and most inefficient port given a score of zero.

Figure D.2 – Statistical and administrative approach broadly comparable[a]

Port rank using each method



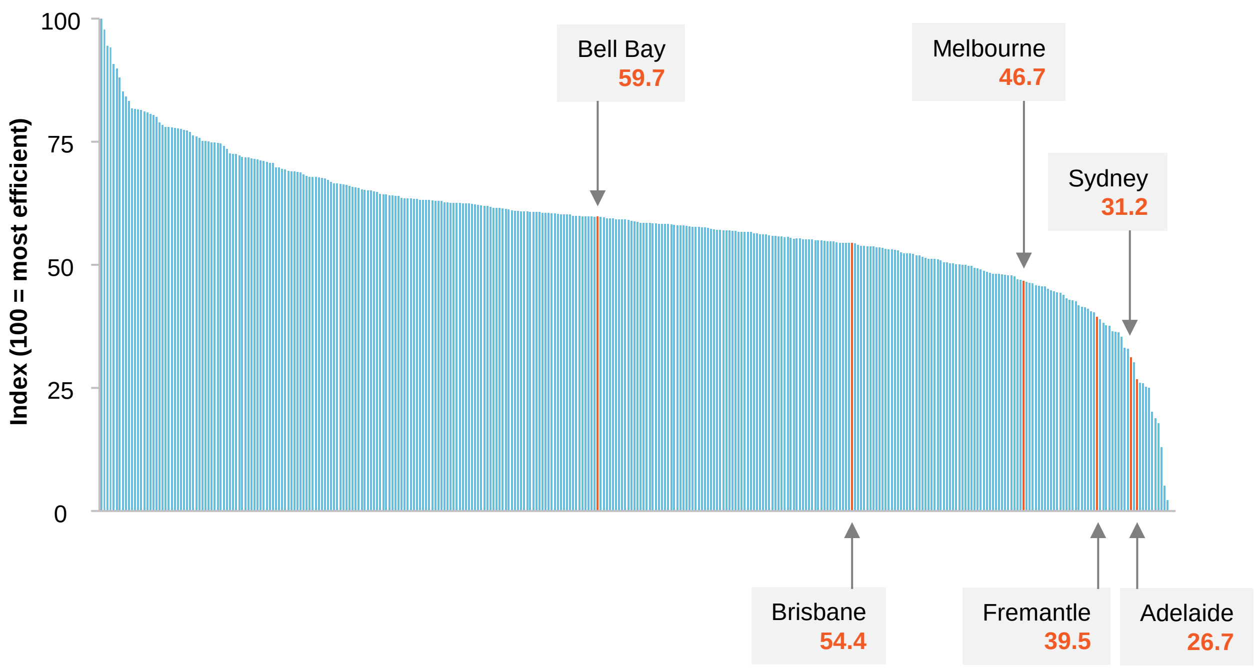
a. There are 351 ports in total. The correlation coefficient between the rankings is 0.91.

Source: Adapted from the World Bank (2021).

Four of the five main Australian container ports ranked in the bottom 20 per cent of the CPPI — meaning they are relatively inefficient (figure D.3). Brisbane was the found to be the most efficient of the main Australian ports, but still ranked in the bottom 30 per cent. The most efficient port was Yokohama in Japan, and the most inefficient port was Ngqura in South Africa.

Figure D.3 – Most of Australia's ports ranked poorly

Each port's efficiency score (CPPI)



Source: Adapted from the World Bank (2021).

Appendix A

Appendix A in the study provides ranking for the administrative approach in each ship size category (that is, before the result for each ship size is aggregated into a weighted average total score). This permits identification of a port's ranking within different ship size groups (across all call sizes). For example, the Port of Melbourne's rankings are:

- Ships <1500 TEUs: nil (Melbourne does not accommodate ships this small)
- Ships 1501–5000 TEUs: 238 out of 331 ports
- Ships 5001–8000 TEUs: 159 out of 213 ports
- Ships 8001–13 500 TEUs: 143 out of 162 ports
- Ships >13 500 TEUs: nil (Melbourne does not accommodate ships this large).

This reveals that the Port of Melbourne is not in the bottom quintile of the ranking when handling ships between 1501-8000 TEUs, but is in the bottom quintile when handling ships between 8001-13 500 TEUs.

Caveats

- While there is an attempt to make fair comparisons by taking into account ship and call sizes docking at ports, there may be other factors that impact on how efficient ports are. For example, transhipment ports will likely have different operations to destination–origin ports, making them more (or less) efficient on average.
- Despite having access to data at a terminal level, the method does not account for differences in productivity levels between terminals (or stevedores) at a port, and rather takes an average. For example, the AMP Terminal in Yokohama outperforms the other container terminals in Yokohama. An interesting extension would be to examine terminal performance.

- The use of an aggregate measure of performance (port hours) does not shed light on which processes at a port are efficient or inefficient. This makes it difficult to make sound operational strategy and policy recommendations. Many ports around the world follow a landlord model, where marine services are managed and operated by port authorities or by specialised companies other than terminal operators. A single CPPI score cannot be used to pinpoint the sources of delays and congestion in a multi-institutional port setting.
- The CPPI does not assess the ability of a port to use and allocate its resources in an economically efficient way. This is a fundamental principle in productive efficiency because a port that unnecessarily throws extra capacity resources to improve berth performance may not necessarily be efficient, yet it could end up achieving a high score under the CPPI. The top 50 ranked CPPI ports are dominated by deep-sea hub ports with ample spare capacity. These are typically located in East Asia and the Middle East and North Africa regions.
- The CPPI is exclusively focused on port operations and quayside performance which is unfairly skewed towards the interests of one set of port customers (shipping lines) and does not address the needs of cargo interests nor cover landside and hinterland sources of port congestion and inefficiency. This could explain the ranking prominence of ports with a high transhipment incidence — the latter require little or no inland and hinterland efficiency. A more holistic view (if data were available) might alter these rankings.

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