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The impact of governance on efficiency: case studies on airports and seaports

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Abstract

Airports and seaports have experienced significant governance reforms over the last few decades. As major airports are argued to have market power, they are subject to some form of economic regulation. Airports used to be subject to rate-of-return regulation. More recently, there has been a reform in airport economic regulation and they are increasingly being subject to incentive based price-cap regulation and light-handed regulation or monitoring. In the policy debate, it is of interest to analyse whether price-cap regulation and light-handed regulation of airports are superior to rate-of-return regulation. In the case of seaports, there has been a reform in their governance model and a large number of seaports now follow the landlord seaport model. In a landlord seaport, the port authority is responsible for monitoring and coordination while specialized private terminal operators are responsible for cargo handling and seaport operations. Policy debates have focused on whether the landlord seaport model leads to superior performance in comparison to the service seaport model where most responsibilities are handled by the port authority or the public sector. Airports and seaports are increasingly being regulated by independent regulators because they are not susceptible to regulatory capture. Policy debates have also focused on whether independent regulators lead to a superior performance in comparison to dependent regulators.

The first part of this thesis focuses on airport regulation and its impact on efficiency. We conduct a literature review of the theoretical and empirical literature on airport regulation and efficiency. We find that dual-till price-cap regulation and light-handed regulation are preferable to rate-of-return regulation from an efficiency perspective. We also find that while light-handed regulation leads to efficient airports, it does not necessarily constrain airport charges and hence does not lead to the cheapest airports. We find that independent regulators enhance airport performance. With respect to slot allocation, we find that slot allocation is superior to queuing in terms of capacity, delay and congestion management. However, we find that slot allocation based on economic principles is superior to administrative slot allocation. In this part of the thesis, we also identify gaps in the empirical literature which require further analysis.

The next part of the thesis focuses on the impact of governance on the technical efficiency of major Indian seaports. This chapter uses a non-oriented slacks based measure of technical efficiency in the first stage and a fixed effects regression in the second stage in order to analyse the impact of governance on the technical efficiency of the major Indian seaports. From the first stage, we find that most of the seaports have a scope for improvement in technical efficiency. From the second stage analysis, we find that specialization has the highest positive impact on technical efficiency. We hence propose that the major Indian seaports have to specialize because they can benefit from economies of scale. With respect to ownership, we find that external stakeholder participation has a significant positive impact on technical efficiency. This gives evidence that the landlord seaport model is conducive to enhanced technical efficiency. With respect to competition, we find that competition from the non-major Indian seaports from within the state and along the coast has a significant negative impact on the technical efficiency of the major Indian seaports. We argue that this is because of the tiered governance framework, which results in excess capacity at the major Indian seaports. We propose that the seaports should have a common governance, institutional and regulatory framework, which can enhance their performance. With respect to regulation, we find that rate-of-return regulation by an independent regulator is superior to internal regulation by the port authority in terms of technical efficiency. We argue that this is because the independent regulator is not susceptible to regulatory capture unlike the port authorities.

The last part of the thesis focuses on the impact of governance on the technical efficiency of container ports from the Far East and Asian region. This chapter uses stochastic frontier analysis in order to estimate a production frontier. It makes use of a single step procedure which can be used to estimate the production frontier as well as to estimate the impact of the governance-related contextual variables on the technical efficiency of these container ports. We estimate the individual as well as the combined effects of the governance-related contextual variables on the technical efficiency of these container ports. From the individual effects model, we find that majority private container ports are significantly more technically efficient in comparison to minority private container ports. This gives evidence that the landlord seaport model is conducive to enhanced technical efficiency. With respect to competition, from the individual effects model, we find that both hinterland and transshipment competition enhance the technical efficiency of these container ports. With respect to regulation, from the individual effects model, we find that regulation by an independent regulator is the most conducive to enhanced technical efficiency. In the combined effects model, a majority private container port which faces high hinterland competition and has no economic regulation is taken as the base case. Most of the other combinations of the contextual variables result in a significantly lower technical efficiency in comparison to the base case. However, a majority private container port which faces low hinterland competition and either has no economic regulation or is regulated by an independent regulator is significantly more technically efficient in comparison to the base case. Our results further show that when a port is majority private and faces low hinterland competition, regulation by an independent regulator results in a significantly higher technical efficiency in comparison to having no economic regulation. We argue that this is caused because there is excessive entry and hence majority private container ports which face low hinterland competition and are regulated by an independent regulator are the most technically efficient. We propose that along with the setting up of independent regulators for container ports, policymakers should also ensure that entry is at an optimal level, which can result in competition that is effective and technical efficiency enhancing.

***Keywords*:** airports, seaports, governance, ownership, competition, economic regulation, efficiency

Zusammenfassung

Flughäfen und Seehäfen haben in den letzten Jahrzehnten erhebliche Reformen des Ordnungsrahmens erfahren. Da man davon ausgeht, dass Großflughäfen über Marktmacht verfügen, unterliegen sie einer gewissen Form der wirtschaftlichen Regulierung. Früher unterlagen Flughäfen der Rate-of-Return-Regulierung. In jüngerer Zeit wurde die wirtschaftliche Regulierung von Flughäfen reformiert, und sie unterliegen zunehmend einer anreizbasierten Price-Cap-Regulierung oder einer Light-Handed-Regulierung. In der politischen Debatte ist es von Interesse zu analysieren, ob die Price-Cap-Regulierung und die Light-Handed-Regulierung von Flughäfen der Rate-of-Return-Regulierung überlegen sind. Bei den Seehäfen hat es eine Reform ihres Ordnungsrahmens gegeben, und eine große Anzahl von Seehäfen folgt jetzt dem Landlord-Seehafenmodell. In diesem Modell ist die Hafenbehörde für die Überwachung und Koordination zuständig, während spezialisierte private Terminalbetreiber für den Frachtumschlag und den Hafenbetrieb verantwortlich sind. Die politischen Debatten konzentrieren sich auf die Frage, ob das Landlord-Seehafenmodell zu besseren Leistungen führt als das Modell des Seehafens als Dienstleister, bei dem die meisten Aufgaben von der Hafenbehörde oder dem öffentlichen Sektor übernommen werden. Flughäfen und Seehäfen werden zunehmend von unabhängigen Regulierungsbehörden beaufsichtigt, um sie vor den Einfluss partikularer Interessen zu schützen Die politischen Debatten haben sich auch darauf konzentriert, ob unabhängige Regulierungsbehörden im Vergleich zu abhängigen Regulierungsbehörden eine bessere Leistung erbringen.

Der erste Teil dieser Arbeit befasst sich mit der Regulierung von Flughäfen und ihren Auswirkungen auf die Effizienz. Wir führen eine Literaturübersicht über die theoretische und empirische Literatur zu Flughafenregulierung und Effizienz durch. Wir kommen zu dem Ergebnis, dass die Dual-Till-Price-Cap-Regulierung and die Light-Handed Regulierung Effizienzgesichtspunkten der Rate-of-Return-Regulierung vorzuziehen sind. Wir stellen außerdem fest, dass eine Light-Handed Regulierung zwar zu effizienten Flughäfen führt, aber nicht notwendigerweise die Flughafengebühren einschränkt und somit nicht zu den billigsten Flughäfen führt. Wir stellen fest, dass unabhängige Regulierungsbehörden die Leistung von Flughäfen verbessern. In Bezug auf die Zuweisung von Zeitnischen stellen wir fest, dass die Zuweisung von Zeitnischen dem Warteschlangenmanagement in Bezug auf Kapazität-, Verspätung- und Engpassmanagement überlegen ist. Wir stellen jedoch fest, dass die marktwirtschaftliche Zuweisung von Zeitnischen der administrativen Zuweisung von Zeitnischen überlegen ist. In diesem Teil der Arbeit werden auch Lücken in der empirischen Literatur aufgezeigt, die eine weitere Analyse erfordern.

Der nächste Teil der Arbeit befasst sich mit den Auswirkungen der Governance auf die technische Effizienz der großen indischen Seehäfen. In diesem Kapitel wird in der ersten Phase ein nicht-orientiertes, auf Slacks basierendes Maß für die technische Effizienz und in der zweiten Phase eine Regression mit festen Effekten verwendet, um die Auswirkungen des Ordnungsrahmens auf die technische Effizienz der wichtigsten indischen Seehäfen zu analysieren. In der ersten Stufe stellen wir fest, dass die meisten Seehäfen einen Spielraum für die Verbesserung der technischen Effizienz haben. In der zweiten Phase der Analyse stellen wir fest, dass die Spezialisierung den größten positiven Einfluss auf die technische Effizienz hat. Wir schlagen daher vor, dass sich die großen indischen Seehäfen spezialisieren müssen, weil sie von Größenvorteilen profitieren können. In Bezug auf die Eigentumsverhältnisse

stellen wir fest, dass die Beteiligung externer Stakeholder einen signifikant positiven Einfluss auf die technische Effizienz hat. Dies deutet darauf hin, dass das Landlord-Seehafenmodell zu einer verbesserten technischen Effizienz beiträgt. In Bezug auf den Wettbewerb stellen wir fest, dass die Konkurrenz der kleineren indischen Seehäfen innerhalb eines indischen Bundesstaates und entlang der Küste einen signifikant negativen Einfluss auf die technische Effizienz der großen indischen Seehäfen hat. Wir argumentieren, dass dies auf den abgestuften Ordnungsrahmens zurückzuführen ist, der zu Überkapazitäten in den großen indischen Seehäfen führt. Wir schlagen vor, dass die Seehäfen einen gemeinsamen institutionellen und regulatorischen Rahmen haben sollten, der ihre Leistung verbessern kann. Im Hinblick auf die Regulierung stellen wir fest, dass die Rate-of-Return-Regulierung durch eine unabhängige Regulierungsbehörde der internen Regulierung durch die Hafenbehörde in Bezug auf die technische Effizienz überlegen ist. Wir argumentieren, dass dies darauf zurückzuführen ist, dass die unabhängige Regulierungsbehörde im Gegensatz zu den Hafenbehörden nicht anfällig für partikulare Interessen ist.

Der letzte Teil der Arbeit befasst sich mit den Auswirkungen der Governance auf die technische Effizienz von Containerhäfen im Fernen Osten und im asiatischen Raum. In diesem Kapitel wird die Stochastische Frontier Analyse verwendet, um eine Produktionsgrenze zu schätzen. Dabei wird ein einstufiges Verfahren verwendet, das sowohl zur Schätzung der Produktionsgrenze als auch zur Schätzung der Auswirkungen der auf den Ordnungsrahmen bezogenen Kontextvariablen auf die technische Effizienz dieser Containerhäfen eingesetzt werden kann. Wir schätzen sowohl die individuellen als auch die kombinierten Auswirkungen der auf den Ordnungsrahmen bezogenen Kontextvariablen auf die technische Effizienz dieser Containerhäfen. Das Modell der individuellen Effekte zeigt, dass private Containerhäfen mit Mehrheitsbeteiligung im Vergleich zu privaten Containerhäfen mit Minderheitsbeteiligung technisch deutlich effizienter sind. Dies deutet darauf hin, dass das Landlord-Seehafenmodell zu einer verbesserten technischen Effizienz beiträgt. Was den Wettbewerb betrifft, so zeigt das Modell mit individuellen Effekten, dass sowohl der Hinterland- als auch der Umschlagswettbewerb die technische Effizienz dieser Containerhäfen verbessern. In Bezug auf die Regulierung zeigt das Modell mit individuellen Effekten, dass die Regulierung durch eine unabhängige Regulierungsbehörde die technische Effizienz am stärksten fördert. Im Modell mit kombinierten Effekten wird ein mehrheitlich privater Containerhafen, der einem starken Hinterlandwettbewerb ausgesetzt ist und keine wirtschaftliche Regulierung hat, als Basisfall angenommen. Die meisten anderen Kombinationen der Kontextvariablen führen zu einer deutlich niedrigeren technischen Effizienz im Vergleich zum Basisfall. Ein mehrheitlich privater Containerhafen, der einem geringen Hinterlandwettbewerb ausgesetzt ist und entweder keiner wirtschaftlichen Regulierung unterliegt oder von einer unabhängigen Regulierungsbehörde reguliert wird, ist jedoch im Vergleich zum Basisfall technisch deutlich effizienter. Unsere Ergebnisse zeigen außerdem, dass ein mehrheitlich privater Hafen, der einem geringen Hinterlandwettbewerb ausgesetzt ist, bei einer Regulierung durch eine unabhängige Regulierungsbehörde eine deutlich höhere technische Effizienz aufweist als ohne wirtschaftliche Regulierung. Wir argumentieren, dass dies darauf zurückzuführen ist, dass es einen übermäßigen Marktzutritt gibt und daher mehrheitlich private Containerhäfen, die einem geringen Hinterlandwettbewerb ausgesetzt sind und von einer unabhängigen Regulierungsbehörde reguliert werden, die höchste technische Effizienz aufweisen. Wir schlagen vor, dass die politischen Entscheidungsträger neben der Einrichtung unabhängiger Regulierungsbehörden für Containerhäfen auch sicherstellen sollten, dass der Marktzutritt auf

einem optimalen Niveau erfolgt, was zu einem effektiven und die technische Effizienz steigernden Wettbewerb führen kann.

***Stichworte*: ** Flughäfen, Seehäfen, Governance, Eigentum, Wettbewerb, wirtschaftliche Regulierung, Effizienz

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List of Abbreviations

3SLS – Three-Stage Least Squares

AA – American Airlines

APM – A. P. Moller-Maersk

BAA – British Airports Authority

BL – Berth Length

BOT – Build Operate Transfer

BP – British Petroleum

CEE – Central and Eastern Europe

CIS – Commonwealth of Independent States

COVID-19 – Coronavirus Disease

DEA – Data Envelopment Analysis

DMU – Decision-Making Unit

DPW – Dubai Ports World

EU – European Union

GDP – Gross Domestic Product

GMM – Generalized Method of Moments

HHI – Herfindahl-Hirschman Index

HPH – Hutchinson Port Holdings

ICAO – International Civil Aviation Organization

IID – Independent and Identically Distributed

IMA – Indian Maritime Agenda

IPA – Indian Ports Association

ITF – International Transport Forum

IV-2SLS – Instrumental Variable Two-Stage Least Squares

JNPT – Jawaharlal Nehru Port Trust

KLEMS – Capital, Labour, Energy, Materials and Supplies

MoS – Ministry of Shipping

MOT/S – Ministry of Transport/Shipping

NC – Number of Cranes

NERA – National Economic Research Associates

NMDP – National Maritime Development Programme

NMPT – New Mangalore Port Trust

NR – No Regulation

OECD – Organisation for Economic Co-operation and Development

OLS – Ordinary Least Squares

PA – Port Authority

PCA – Principal Components Analysis

RAB – Regulated Asset Base

RPI – Retail Price Index

RTS – Returns to Scale

SBM – Slacks Based Measure

SFA – Stochastic Frontier Analysis

SIP – Share Issue Privatization

SOE – State Owned Enterprises

SURE – Seemingly Unrelated Regression Equations

TA – Terminal Area

TAMP – Tariff Authority for Major Ports

TC – Technical Change

TEU – Twenty-Foot Equivalent Unit

TFP – Total Factor Productivity

TH – TEU Handled

UK – United Kingdom

UNCTAD – United Nations Conference on Trade and Development

US – United States

WPI – Wholesale Price Index

Table of Contents

List of Tables

List of Figures

Chapter 1

Introduction

1.1. Background

This PhD thesis is a cumulative dissertation containing three research papers all of which focus on facets of governance and their impact on efficiency. While the focus of this chapter is on public utilities and transport in general, the focus of Chapter 2 is on airports and Chapter 3 and Chapter 4 focus on seaports. The vital facets of governance are ownership, competition and economic regulation and their efficiency implications are the focus of this research. The third and fourth chapters of this thesis focus on the impact of governance on the efficiency of seaports and the second chapter focuses on economic regulation and its implications for airport efficiency. With respect to ownership, previous research has focused on whether public or private firms are more efficient. However, in this research, the focus is on public-private partnerships as these are the most prevalent among seaports. It should however be noted that ownership in itself will not lead to more efficient outcomes. An efficient outcome is a function also of the competitive environment as well as the regulatory environment that the firm is facing and Vickers and Yarrow (1988) argue that competition and regulation are often more important than ownership in determining whether an industry and the firms contained in the industry will be efficient. As a result, Chapters 3 and 4 will also include measures of competition in measuring the efficiency of seaports. With respect to regulation, when there is no effective competition, economic regulation may be necessary in containing the market power of firms that may be considered natural monopolies. Chapter 2 will hence focus on airport regulation by conducting a survey of papers that have analysed airport regulation and efficiency. Chapter 3 will include economic regulation as an explanatory variable in determining the efficiency of seaports and Chapter 4 will measure the impact of institutional regulation on the technical efficiency of container seaports.

The objective of this chapter is to set Chapter 2, Chapter 3 and Chapter 4 in the broader context of how governance influences efficiency. It will do so by reviewing some of the theoretical and empirical literature on governance and efficiency. Section 1.1.1 will review the literature that has analysed the performance impact of ownership. Section 1.1.2 will review the literature that has analysed the performance impact of competition and Section 1.1.3 will review the literature that has analysed the performance impact of economic regulation. Section 1.2 will thereafter focus on benchmarking techniques and Section 1.3 will finally provide some concluding remarks.

1.1.1. Performance Impact of Ownership

Sheshinski and Lopez-Calva (2003) survey the theoretical and empirical literature on privatization to arrive at conclusions on the benefits of privatization. With respect to profitability, they find that private companies perform better than public companies in a competitive environment. They also find that partial privatization leads to lower profitability in comparison to full privatization. With respect to efficiency, they find that privatization leads to efficiency gains in competitive sectors. However, these gains are lower in markets that are more concentrated and regulated. Productivity of partially privatized firms is less than that of fully privatized firms. Combining the two, they find that both profitability and efficiency gains are only realized in competitive markets. In less competitive sectors, firms use their market power, which affects the consumer surplus, although the welfare changes of privatization are positive. With respect to the public sector's financial health, they find that privatization is an important policy tool for fiscal reform as it lowers public sector deficits and debt. With respect to the performance of state owned enterprises (SOEs), they find that privatization leads to a reduction in the amount of subsidies provided to these firms. In fact, they find that after privatization, the government receives taxes from previously money-losing firms. Along with a positive impact of the public sector's financial health, the authors find that privatization also has a positive impact on the development of the financial sector. With respect to employment, they find that privatization has a negative impact on employment in the short-run, but a positive impact on employment in the medium- and long-run. With respect to distribution and poverty, they show that the impact of privatization has a positive result. However, they argue that research in this area is scarce and further research may be needed in order to estimate the impact of privatization on distribution and poverty.

Early papers that have measured the performance impact of ownership focus on factors such as profitability, factor productivity, and unit cost levels (Vickers and Yarrow, 1988). Yarrow (1986) analyses the performance impact of privatization in the UK. He finds that privatization of National Freight Corporation and Cable and Wireless have been successful because they operate in a relatively competitive environment. However, he finds that this is not the case with the privatization of firms such as BP, Britoil and British Aerospace. In the case of British Telecom, he finds that privatization may have adverse consequences because attention had not been paid to limiting the abuse of monopoly power by the firm. He concludes that privatization has resulted in a small group of investors having windfall gains at the expense of taxpayers.

Florio (2004) analyses the welfare effects of the British privatizations from 1979 to 1997. He finds there there is no productivity increase in the privatized British industries. He argues that this is because the governance of these industries was a complex game among small control groups of financial investors, executive directors, and regulators. He argues that such coalition ownership does not give firms' executive directors with an incentive to pursue strategies to save on production factors. He argues that executive directors in such industries focus on profitability and not productivity. He further argues that privatization did not result in strong efficiency gains because the nationalized industries were also relatively efficient and the privatized industries did not have incentives to pursue innovation, productivity growth, or endogenous cost savings. Analysing social-welfare changes, he finds that there is no substantial impact of divestitures on aggregate growth. He finds that the impact of privatization on employment, inflation, and income distribution were respectively neutral, modestly favourable, and unfavourable. He finds that the privatization game had various stakes, which cancelled each other out. For example, benefits for buyers were losses for sellers; excess profits for shareholders were losses for consumers; and high salaries for managers were costs for the firms. He finds that the redistributive effects of privatization are not negligible. He finds that net beneficiaries of privatization were those that belonged to the wealthiest 10-20 percent of the population. However, those who bore the net welfare costs of privatization were those that belonged to the poorest 10-20 percent of the population. He concludes that the net welfare benefits of privatization in United Kingdom are modestly positive and these values may even become negative when the distribution of income and wealth are taken into account.

Pryke (1982) compares the performance of public and private firms in civil aviation, short sea ship and hovercraft services, and the sale of gas and electric appliances and contracting in the UK. He finds that the private firms perform better than the public firms in all three sectors with respect to profitability and efficiency. He argues that the poor performance of firms in the public sector is most likely because they do not provide services on a commercial basis. He argues that their services are like social services that take the national interest into account. Another reason that he provides is that public ownership eliminates the threat of takeover, and ultimately of bankruptcy and the need to raise money from the market. He argues that this in turn provides a comfortable life and destroys the commercial ethic in public firms.

With regards to particular sectors, there has been some research on the performance of public versus private firms in the electricity supply and generation sector. Meyer (1975) analyses the performance of public and private power generation firms in the United States in 1967, 1968 and 1969. He finds that the mode of ownership makes an economic difference. His analysis shows that private firms have higher costs than public firms and he argues that this may be because of the regulatory environment. The private power generation firms are subject to rate-of-return regulation and he argues that the higher costs may be due to the Averch and Johnson (1962) effect. He also focuses on two other factors that may be leading to the cost differences. Public power generation firms may be able to purchase inputs at lower prices and they may be employing technologies with a lower operating cost. He eventually compares the sales and average revenues of the two types of firms and finds that private firms have higher average prices, which may be due to the existence of cost differences.

Pescatrice and Trapani (1980) arrive at similar conclusions as Meyer (1975) by comparing the production efficiency of public and private utilities in the United States. They find that public firms minimize costs and have 24-33% lower per unit costs in comparison to their privately owned counterpart. They argue that this is due to rate-of-return regulation of the privately owned firms. Färe et al. (1985) compare the performance of 123 private and 30 public electric utilities in the United States in 1970. They find that there is no significant difference in overall efficiency and allocative efficiency between the public and private electric utilities in their sample. However, they find that publicly-owned utilities perform better than privately-owned utilities in terms of pure technical efficiency. Moreover, they also find that private utilities are more likely to be uncongested and at an optimal scale in comparison to public utilities.

With respect to pricing, Peltzman (1971) and De Alessi (1977) find that privately-owned electric utilities are more likely to practice peak-load pricing in comparison to publicly-owned electric utilities. As time-of-day pricing can lead to a higher allocative efficiency of the electric utility (Vickers and Yarrow, 1988), one could argue that privately-owned electric utilities have a higher allocative efficiency in comparison to publicly-owned electric utilities. This is however not the case and Vickers and Yarrow (1988) argue that areas where the quality of regulation is regarded as high are the ones where time-of-day pricing is more common. Moreover, they also argue that Britain and France were the early proponents of peak-load pricing, when the electric utilities were publicly-owned.

There has also been some research on the comparison of public and private firms in the water industry. Crain and Zardkoohi (1978) compare the economic efficiency of 24 private and 88 public water utilities in the United States in 1970. Their results show that operating costs are significantly higher for public water utilities in comparison to private water utilities. They attribute these cost differentials to a difference in labour productivity with private utilities having a higher labour productivity in comparison to public utilities. They conclude that private water utilities have a higher economic efficiency in comparison to public water utilities because of the nontransferability of ownership shares in public firms, which reduces the incentive to monitor managerial conduct, which in turn leaves such firms susceptible to less efficient operation. However, contrary to their results, Bruggink (1982) finds that public water utilities have a lower unit cost in comparison to private water utilities.

In the case of refuse collection, Savas (1977) compares the efficiency of public and private refuse collection firms in 315 cities in the United States. He finds that contract collection, wherein the city contracts out refuse collection to the private sector, is the least costly service arrangement for households, implying a higher efficiency of such firms. By analysing a sub-sample of 177 and 262 cities, Savas finds that municipal waste collection is between 29 to 37% costlier for the households in cities with more than 50,000 people in comparison to contract waste collection. In terms of the cost of production, Savas finds that municipal firms have a 25% higher cost in comparison to the private firms. He shows that the greater price and the lower cost efficiency of municipal refuse collection firms are caused because they have higher employee absentee rates, employ larger crews, serve fewer households per shift, spend more time servicing each household, and are less likely to use labour-incentive systems.

Stevens (1978) analyses the cost to households of 340 public and private refuse collection firms distributed in cities throughout the United States. She finds that for cities with a population of over 50,000 people, total costs to households is significantly less when service is provided by a private monopolist than when service is provided by a public monopolist. She finds that this is because labour productivity is lower in the public monopoly arrangement than in the private monopoly arrangement. She concludes that it is desirable to ensure an exclusive market area to a single producer, provided that the producer is a private firm. She also concludes that rate regulation is of average effectiveness and that contract letting procedures can ensure reasonable competitiveness.

With respect to the British steel industry, Rowley and Yarrow (1981) study the performance of the industry pre-nationalization with rate-of-return regulation and post-nationalization from 1957 to 1975. They find that nationalization has led to a downturn in all significant indicators of performance. As one could argue that this might have occurred because of the structural change in the British economy, the authors highlight that this does not receive empirical support because the post-nationalization period witnessed significant improvements in the overall productivity of British industry.

With respect to transportation, Caves and Christensen (1980) compare the total factor productivity of two Canadian railway companies namely Canadian National and Canadian Pacific Railroads from 1956 to 1975. Out of these two, Canadian National was government owned and Canadian Pacific Railroads was privately owned. As the two railway companies compete with each other, they find that the total factor productivity has increased at a rapid rate for both companies. They cite competition as the main factor that has resulted in the offsetting of the negative aspects of public ownership.

Based on their review of the literature on privatization, Megginson and Netter (2001) offer some interesting conclusions. They find that privatization has significantly reduced the role of state-owned enterprises (SOE) and SOE share as a percentage of global gross domestic product

(GDP) has declined from 1979 to 2001. They find that privately owned firms are more profitable, more efficient and financially healthier in comparison to state-owned firms. Of the three techniques of privatization namely share issue privatizations (SIPs), asset sales and voucher or mass privatizations, they find that voucher privatizations are the least economically productive divestment technique. They find that most governments underprice share offerings and then use targeted share allocations to favour domestic over foreign investors. With respect to employment, there is no clear consensus of whether privatization leads to a loss in jobs. This is mainly a function of whether sales increase faster than productivity in privatized firms. With respect to returns, they find that investors who purchase initial SIP shares at the offering price and those that retain the shares for one-, three-, or five-year holding periods, earn significantly positive net returns. They find that countries which have launched large-scale SIP programs have experienced rapid growth in their national stock market capitalization and trading volume. They also find that large-scale SIP programs modernize a nation's corporate governance system. On the whole, they find that privatization through SIPs has positive impacts in terms of efficiency, profitability and financial health.

Kikeri and Nellis (2004) have surveyed the literature on privatization and the performance of privatized firms worldwide. Based on the literature, they argue that privatization and private participation usually improves the financial situation of the firm as well as the fiscal situation of the selling government, increases returns to shareholders, and generates significant welfare benefits. They also highlight that the costs of no or slow privatization can be high. However, they argue that prior to privatization, countries should develop and protect competitive forces, create proper regulatory frameworks, introduce and enforce transparency in sales processes, develop social safety nets for the adversely affected, and introduce innovative pricing and subsidy mechanisms to ensure that the poor have access to affordable essential services.

Estrin et al. (2009) review the literature on the performance of privatized firms in transition economies. They find that privatization to foreign owners results in improved performance of firms. Privatization to domestic owners has varying performance impacts. It is positive but often delayed in Central and Eastern European (CEE) countries. However, the performance impact of privatization to domestic owners is absent or even negative in Russia and the rest of the Commonwelth of Independent States (CIS). They argue that this is because the CEE countries adopted EU rules while the CIS were slow in introducing a market friendly legal and institutional system. In China they observe that privatization to domestic owners enhances performance and they argue that this is because of the gradual reform process. They find that private ownership has a positive impact on performance in comparison to dispersed ownership in CEE and the CIS. In the case of China, they find that foreign joint ventures have a higher level of total factor productivity in comparison to wholly owned foreign firms. They find that worker ownership of firms in CEE, the CIS and China does not seem to have a negative impact on performance. They find that new firms in CEE and the CIS perform better than firms privatized to domestic owners and foreign start-ups are more efficient than domestic ones. With respect to employment, contrary to most of the studies, they find that privatized firms in post-communist transition economies tend to keep employment at a higher level in comparison to state-owned firms. They find that privatization along with complementary reforms leads to a higher level of aggregate output or economic growth. They conclude that privatization in itself does not lead to improved performance. They argue that the type of private ownership, corporate governance, access to know-how and markets, and the legal and institutional system matter for firm restructuring and performance.

Willner (2003) reviews the theoretical and empirical literature on public and private ownership. He shows that neither theory nor empirical evidence prove that private ownership leads to cost reductions in comparison to public ownership. He argues that in some instances competition in the product market may not be desirable or even feasible, which strengthens the case against privatization. He also argues that privatization is less desirable because the policy is costly to reverse if it turns out to be wrong. He concludes that arguments for public ownership should consequently be reconsidered.

Mühlenkamp (2015) reviews the theoretical and empirical literature on privatization and arrives at very different conclusions than Megginson and Netter (2001). He argues that there is heterogeneous empirical evidence on the relative economic performance of public and privately owned enterprises. Firstly, he argues that the increased threat of privatization forced the managers of public enterprises to introduce management reforms which has improved their performance. Secondly, he argues that the difference in the performance of public and private enterprises is less in industrialized countries as opposed to developing or transition economies. He points out that this is because of better institutional frameworks in industrialized countries. Thirdly, he argues that the performance of public or private enterprises is also a function of the competition that they face. He highlights that while some studies find that in a competitive environment the distinctions between public and private enterprise diminish, other studies find that privatization is preferable in markets with full competition. Fourthly, he argues that there is no difference between public and private production under a regulation regime. In fact, several authors find less advantage of private ownership provided that market failure exists. The fifth point he identifies is the measure of performance. He argues that using profitability as a measure of performance may be misleading. He instead proposes that studies should use productive efficiency, cost efficiency and social welfare as the performance indicator. He finds that public enterprises do not lose or even win the contest when the latter measures are used as the performance indicator. Moreover, as privatization is argued to have regressive distribution effects, public enterprises may be more preferable when distribution effects are taken into account. He concludes that evidence does not support the view that private enterprises perform better than public enterprises and he argues that policy should focus on the right competitive and regulatory environment because this is what impacts the performance of firms.

Having reviewed some of the literature on the performance impact of public and private ownership, we find that both forms can lead to better performance and this is mainly dependent upon the competitive and regulatory environment in place. We now turn our focus to the performance impact of public-private partnerships. As already noted, Sheshinski and Lopez-Calva (2003) find that mixed enterprises have lower profitability and productivity levels in comparison to privatized firms.

Boardman and Vining (1989) compare the performance of private corporations, state-owned enterprises and mixed enterprises that are among the 500 largest non-U.S. manufacturing and mining firms in 1983 that operate in a competitive environment. They find that state-owned enterprises and mixed enterprises are significantly less profitable and less efficient than private corporations. With respect to profitability, they find that mixed enterprises perform about the same or worse than state-owned enterprises. With respect to efficiency, they find that mixed enterprises perform about the same or slightly better than state-owned enterprises. The authors conclude that partial privatization may be worse than either full privatization or public ownership especially in terms of profitability. The authors argue that this is caused due to conflict generated between public and private shareholders leading to a high degree of managerial cognitive dissonance.

With respect to seaports, there has been significant reforms in their governance framework. The most important governance model for this thesis is the landlord seaport model. According to the World Bank (2001), the landlord seaport model contracts out port operations to the private sector, and the terminal operator thereafter invests in the superstructure, which is the cargo-handling technology. The terminal operator is in turn eligible to earn returns on the investments made for a predetermined concession period. Under the landlord seaport model, common port infrastructure is either funded by the port authority, by the private sector, or through a public-private partnership agreement. This is in contrast to the public service seaport model which was common before the emergence of port reforms. In a public service seaport model, the port authority is responsible for port planning, management and operations. However, in the public service seaport model, minor services such as nautical-technical services may be provided by a private firm, a group of private firms, the port authority or a public-private partnership agreement.

While studies such as Liu (1995), Cullinane et al. (2005a) and Notteboom et al. (2000) find that ownership structure has no significant impact on the performance of seaports, a majority of the studies find that private participation and the landlord seaport model have a positive impact on the performance of seaports. For example, Cheon et al. (2010) analyse the performance of 98 global container ports for the years 1991 and 2004, finding that the total factor productivity of these ports is positively correlated with ownership restructuring, with a higher degree of private involvement. Wanke and Barros (2015) show that a higher level of private participation at the major Brazilian seaports leads to significantly higher scale efficiency due to the operational flexibility of the private terminal operators. Wang et al. (2013) show that landlord ports in the USA have a higher profit efficiency in comparison with operating ports. In the case of Chinese ports, Yuen et al. (2013) find that a majority of foreign investment with a minority of Chinese controlling stake has a significant positive impact on technical efficiency. There are further studies such as Cullinane et al. (2006) for container ports worldwide, Chang and Tovar (2014b) for Chilean and Peruvian port terminals, Wanke et al. (2011) and Lopez-Bermudez et al. (2019a) for Brazilian port terminals, and Lopez-Bermudez et al. (2019b) for Argentinian container terminals, which show that private participation has a positive impact on the performance of seaports. Studies such as Sarriera et al. (2013) and Serebrisky et al. (2016) for container ports in Latin America and the Caribbean, Trujillo et al. (2013) for container ports in Africa, and Suarez-Aleman et al. (2016) for container ports from developing countries, also show that the landlord seaport model enhances technical efficiency.

Contrary to the results obtained by Boardman and Vining (1989) and Sheshinski and Lopez-Calva (2003), a majority of the applied literature for seaports shows that public-private partnerships can be performance enhancing. What could be the reason for such an outcome? The intuition is provided in Yuen et al. (2013) and Zheng and Yin (2015). Yuen et al. (2013) argue that the specialization of the terminal operator coupled with the public stakeholder's knowledge of the upstream and downstream markets can enhance the performance of the landlord seaport. Zheng and Yin (2015) argue that ports operating with public-private partnerships get state support in providing transportation infrastructure and preferential policies from the government, which can enhance cost efficiency.

The objective of this thesis is to further study the performance impact of the landlord seaport model. This thesis explores this topic by also controlling for competition and regulation to test whether the positive impact of public-private partnerships in seaports holds after having accounted for these factors. Chapter 3 analyses this for a dataset of Indian seaports. We find that external stakeholder participation has a positive impact on the technical efficiency of the major Indian seaports. This gives evidence that the landlord seaport model is conducive to enhanced performance. Chapter 4 analyses the individual and combined effects of ownership, competition and regulation for a dataset of Asian container ports. From the individual effects model, we find that majority private ports are significantly more technically efficient in comparison to minority private ports. From the combined effects model, we find that a majority private port that has low hinterland competition and has an independent regulator is the most technically efficient. This also gives evidence that the landlord seaport model is conducive to enhanced technical efficiency.

1.1.2. Performance Impact of Competition

Stucke (2013) analyses the benefits and drawbacks of competition. With respect to benefits, he argues that competition lowers costs and prices for goods and services, improves their quality, encourages product differentiation, leads to more innovation, enhances efficiency and productivity, promotes economic development and growth, promotes greater wealth equality, promotes a stronger democracy by dispersing economic power, and promotes greater wellbeing by promoting individual initiative, liberty, and free association. As competition can have many benefits, we will first briefly review the literature on the performance impact of competition.

Armstrong and Sappington (2006) analyse anti-competitive and pro-competitive liberalization policies. They argue that policies that aid some competitors and handicap others can have a negative impact on the development of long-term competition. They argue that policies such as establishing temporary monopolies or oligopolies, excluding foreign investors, specifying market share targets for industry suppliers, providing entrants with long-term subsidized access to the incumbent's infrastructure, restricting the incumbent's pricing flexibility, and imposing unfunded carrier-of-last-resort obligations exclusively on incumbent suppliers generally are not recommended. In contrast, policies that remove barriers to entry and empower consumers are recommended because they foster long-term industry competition. Policies like reducing customer switching costs, rebalancing the incumbent's prices to better reflect its operating costs, privatizing state-owned enterprises, prohibiting predatory pricing, and establishing appropriate access prices for the use of critical infrastructure generally are recommended. They also add that the industry should be closely monitored by the regulator during the liberalization process.

MacDonald (1989) analyses the impact of the Staggers Act on innovation and competition in the railroad sector for grain transportation in the United States. He finds that there is a significant decline in the rates for grain transportation after the Staggers Act was implemented. He argues that this is because of deregulation and the introduction of competition between railways in some regions in the United States. He also shows that the Staggers Act has led to innovation. He observes that there is a rapid spread of multi-car and unit-train shipments and a sharp decline in single-car movements. He also finds that railroads may be ceding much of the short-haul gathering function to trucks while at the same time reclaiming medium-distance traffic from trucks. He concludes that new and effective interrail competition was introduced due to the Staggers Act and as a result of deregulation.

Gonenc and Nicoletti (2000) analyse the links among liberalization, private ownership, competition, efficiency and airfares in the air passenger transporatation industry. They use data for 27 OECD countries and for 102 air routes connecting 14 major interntional airports. The preliminary analysis of their data shows that only a few international routes are truly open to competition. However, from their regression analysis, they find that productive efficiency increases and fares decline when regulation and market structure are friendly to competition. They find that a low market concentration leads to higher productive efficiency. They also find that in liberal environments, fares decline due to actual competition between carriers. They show that business and economy fares are lower in liberalized markets with low concentration. However, they find that these fares increase when markets are dominated by airline alliances. Finally, they find that discount fares are affected by the market environment, charter regulations and the presence of challenger airlines at the route level. This gives evidence that competition has a positive impact on productive efficiency and tends to lower airfares.

Greenfield (2014) analyses the relation between competition and service quality in the US airline industry from 2005 to 2010. His results indicate that routes that experienced a relative decrease in concentration also experienced a relative decrease in delays, which is his measure of service quality. This means that consumers in markets that experience consolidation will experience a relative decline in service quality, which will leave them worse off than otherwise. As mergers increase concentration, he simulates the impact on service quality of the merger between American Airlines (AA) and US Airways (US). His simulations show that the merger would impose costs of between $70 and $105 million on passengers flying on affected airport pair routes because of the increase in delays due to the merger. Studies such as Mazzeo (2003) and Rupp et al. (2006) also find superior airline on-time performance in less concentrated airport-pair markets. All these studies provide evidence that competition leads to a higher level of service quality.

McGinnis (1990) analyses the relative importance of cost and quality of service in competition in freight transportation in the United States after deregulation. He finds that shippers value quality of service more than the cost of service in freight transportation. He however emphasizes that freight rates offered by the carriers do matter because his review reveals that some quality of service indicators are less important in comparison to freight rates while the others are more important in comparison to the freight rates. He proposes that price becomes a major factor after service objectives have been met. He foresees a market where transportation providers face service-demanding shippers and competition in price from other freight transportation providers. He concludes that freight transportation providers should constantly seek service advantages in order to minimize the effect of direct price competition.

With respect to competition for the market, Smirnova and Leland (2016) analyse the role of market power and competition in contracting out of public transit services. They use a data set of buyers and sellers that provide transit services across the United States that spans from 2004 to 2006. By analysing individual contracts, they find that private vendors who have high market power often result in no efficiency or effectiveness gains for government agencies. They argue that if the government agency does not contract out with multiple vendors, they might be captured by one very powerful vendor. They also find that the most expensive contracts are represented by one contract with just one vendor for all operations. They further find that a government agency which has multiple vendors leads to greater vehicle efficiency, smaller fare revenues, smaller contracts, and smaller overall operating expenses per contract. They conclude that competition for the provision of services influences the efficiency and performance of individual contracts.

While most of the studies mentioned above show that competition enhances performance, there are also cases where competition could harm performance. This is mainly so in the case of excessive entry which may result in overcapacity, implying that high competition reduces efficiency. This result is in line with the theory of excessive entry (Mankiw and Whinston, 1986), wherein entrants steal business from incumbents and lower the output per firm resulting in loss of social welfare and reduced firm efficiency. Empirical research on excessive entry includes Berry and Waldfogel (1999) for radio broadcasting, Hsieh and Moretti (2003) for the real estate industry, Hortacsu and Syverson (2004) for the mutual fund industry, and Davis (2006) for the motion picture exhibition market. Hortacsu and Syverson (2004) show that excessive entry harms overall social welfare in the mutual fund industry. Berry and Waldfogel (1999) and Davis (2006) show that excessive entry results in business stealing, which leads to a loss in overall social welfare and overall social inefficiency in the radio broadcasting and motion picture exhibition markets, respectively. Moreover, Hsieh and Moretti (2003) show that the business-stealing effect leads to overall social inefficiency and reduces the productivity of real estate agents.

Knatz (2017) analyses how competition is changing port governance in the United States for the period 2007 to 2016. During this period, there has been some major changes to the industry. Port competition has increased due to a consolidation of the ocean carrier industry. Forecasts have suggested that there is going to be a slower growth rate of US container trade. There has been increasing port congestion on the US West Coast. The expansion of the Panama Canal has opened the potential for shifting trade lanes. The US government and the State governments have been taking steps to withstand increasing port competition. There has also been changes at the local level as ports are entering into strategic collaborations thus shifting their role from traditional landlords to supply chain participants. She finds that there is an increasing potential for over-investment, stranded assets and market share losses due to increasing competition thus providing evidence from the seaport sector for Mankiw and Whinston's (1986) theory. She foresees regional collaboration, governance changes and terminal operator collaboration, which can enhance their market power, hence making it possible for the ports to sustain increasing competition.

There are some other circumstances where competition can harm efficiency. The first is if an industry is a natural monopoly. If it is a natural monopoly, then competition may be undesirable because two or more suppliers can only supply the industry output at higher costs and this can harm efficiency. The second is the empty core problem (Button, 2010). When firms compete with each other, prices may be driven down to such an extent that full costs are not recovered. As a result of this, firms might withdraw a service or go out of business. In the long term, potential investors will reduce or cease to put new investment into the industry. The empty core problem occurs when there are large fixed costs, avoidable costs, indivisibility, network effects and severe fluctuations in demand. The market may be unsustainable also if suppliers enjoy institutional or financial protection, and when there are significant variations in the costs of suppliers. The empty core problem can lead to two outcomes. When suppliers think that they can win the contest, there will be market instability as suppliers keep entering and leaving the market. In case suppliers are more rational, they will not enter the market and there will be a suboptimally low capacity provided. As a result, the empty core problem can also harm efficiency, which occurs because of competition between suppliers. The third is the case of destructive competition. This occurs when there are too many producers in the market which leads to excess capacity. As a result, prices are driven down to such an extent that none of the producers will be able to recover costs or make profits. Many producers may thus exit the industry as they are not able to recover costs. Destructive competition is thus another case where competition can harm efficiency.

Meersman et al. (2011) analyse competition in the seaports sector. They find that there has been a wave of merger activities and increased cooperation as ports are trying to benefit from economies of scale and from the control over logistics chains. They observe that there is increasing concentration among terminal operators, which has increased their market power. As there is also vertical integration among shipping lines and terminal operators, they argue that this has increased their market power and concentration. They argue that apart from providing freight-handling capacity, the concession policy and the port dues, port authorities have to take a more active position in the concentration movement by entering into strategic alliances of their own. They conclude that the increasing concentration and reducing competition among shipping lines and terminal operators with reducing power of the port authorities requires intervention by a regulator, who can remove barriers to entry, regulate tariffs and guarantee a good quality of service.

As seaports are parts of complex trade networks, competition occurs at hierarchical levels (Verhoeff, 1981). In the extant literature, the impact of competition on performance has been analysed for regional inter-port competition between container ports globally (Oliviera and Cariou, 2015); regional inter-port competition between European container ports and Brazilian container terminals (Notteboom et al., 2000; Merkel, 2018; Lopez-Bermudez et al., 2019a); inter- and intra-port competition among Chinese container terminals (Yuen et al., 2013); intra-port competition among container ports in Latin America and the Caribbean (Perez et al., 2016); and transshipment competition among container ports (Notteboom et al., 2000; Cullinane et al., 2006; Sarriera et al., 2013; Suarez-Aleman et al., 2016; Perez et al., 2016).

Merkel's (2018) analysis of the European container ports shows a significantly higher technical efficiency for container ports locked in regional competition within a Euclidean distance of 300 km, hence proposing the promotion of competition between European container ports. Perez et al. (2016) study the technical efficiency of 40 container ports in 19 countries from Latin America and the Caribbean from 2000 to 2010 while also analysing the effects of intra-port competition on efficiency. The authors find that ports with three or four container terminals are more technically efficient than ports with one or two container terminals. The authors suggest that future policies should promote intra-port competition.

The Oliviera and Cariou (2015) results show a significant negative impact of inter-container port competition on efficiency between competitors located within a great circle distance of 400–800 km. Lopez-Bermudez et al. (2019a) find that the technical efficiency of the Brazilian terminals has dropped from 66% in 2008 to 51% in 2017. They cite competitive effects as the main reason for this drop in efficiency.

Yuen et al. (2013) obtain mixed results regarding the performance impacts of competition among container terminals in China. They show that inter- and intra-container port competition has positive impacts on technical efficiency, whereas inter-container terminal competition is shown to have significant negative impacts on efficiency growth. It is argued that the negative impact of inter-container terminal competition on the Malmquist DEA efficiency-growth estimates is due to the free rider problem and the late mover advantage. Trade-oriented regions invest heavily in port infrastructure, and incumbents incur significant costs in shaping the regional port-oriented supply chain, which may lead to over-investment. New entrants then free ride on the incumbents' investment without the need for additional investments in the region's port-based knowledge creation and supply chain orientation. Notteboom et al. (2000) find that the maximum efficiency level obtained in their analysis is 85%, and the authors argue that the analysed European and Asian container terminals have overcapacity to address competition. On the other hand, they also find that small terminals located at larger container ports achieve higher technical efficiency levels due to the cargo generating effect of the port, availability of port operating know-how, and higher intra-port competition.

Regarding transshipment competition, Cullinane et al. (2006) show that transshipment ports are more technically efficient than gateway ports. They argue that this is because transshipment ports are more competitive and focus more on technical efficiency due to the footloose nature of transshipment traffic. Notteboom et al. (2000) also find that hub port terminals achieve a higher level of technical efficiency than feeder port container terminals. Sarriera et al. (2013) find that transshipment ports in Latin America and the Caribbean are more technically efficient than ports that do not handle transshipment traffic. Suarez-Aleman et al. (2016) find that transshipment ports in developing countries have a significantly higher output than ports that are not transshipment hubs. In contrast, Perez et al. (2016) find that transshipment ports are less technically efficient than non-transshipment ports.

In this thesis, the objective is to study the impact of competition on technical efficiency in a broader governance-related framework. Chapter 3 studies the impact of competition in a tiered governance framework of Indian seaports. We find that competition between major and non-major Indian seaports from within the state and along the coast harms the technical efficiency of major Indian seaports. We argue that this is caused because of the tiered governance framework, which leads to excess capacity in the major seaports, thus harming their technical efficiency. Chapter 4 studies the impact of both hinterland and transshipment competition on the technical efficiency of container ports in the Far East and Asian region. From the individual effects model, we find that both hinterland and transshipment competition have a positive impact on the technical efficiency of the container ports. However, from the combined effects model, we find that ports which are majority private, face low hinterland competition and are either subject to no regulation or are regulated by an independent regulator are the most technically efficient. We argue that this is occurring because of excessive entry. As a result of excessive entry, ports which are majority private, face high hinterland competition and have no economic regulation are significantly less technically efficient in comparison to ports which are majority private, face low hinterland competition and have an independent regulator. We propose that policymakers should ensure that entry is at the optimal level, which can result in effective efficiency enhancing competition.

1.1.3. Performance Impact of Regulation

There are three types of regulation which are of importance to this thesis. These are rate-of-return regulation, incentive based price-cap regulation and light-handed regulation or monitoring. With rate-of-return regulation, an asset base is defined and the regulated firm is allowed to earn a certain rate-of-return on the defined asset base. As a result of this regulatory mechanism, what we obtain is the price level that the firm is allowed to charge in order to receive the required rate-of-return on the defined asset base (Sherman, 1989, p. 189). Price-cap regulation fixes a firm's price path over time and as a firm's price level is not related to costs, the firm has an incentive to minimize its costs. This is because there is no downward revision in price if the firm is able to cut costs which means that the firm retains the profits earned by being cost efficient. One form of price-cap regulation is known as RPI-X regulation where some of the gains from cost efficiency are passed on to consumers when the price-caps are reviewed. The prices are adjusted in accordance with an increase in the retail price index (RPI) minus the X term which accounts for the productivity gains of the firm. As a result, real prices decrease over time which ensures that some of the gains from the firm's cost efficiency are passed onto the consumers (Cowan, 2002). With light-handed regulation, there is no explicit economic regulation but instead the regulatory institution closely monitors the conduct of the regulated utility and intervenes in case there is an abuse of market power by the regulated utility. Another feature of this form of regulation is that agreement between the producer and customer on price and quality of service is reached through negotiated settlements with supervision by the regulator (Schultz, 1999; Doucet and Littlechild, 2006). As each one of these types of regulation has its own benefits and drawbacks, it is of interest to briefly review the empirical literature on the performance impact of economic regulation.

There are many studies that analyse how benchmarking can be applied for incentive regulation and yardstick competition. Some examples are Thanassoulis (2000a), Thanassoulis (2000b), Jamasb and Pollitt (2001), Thanassoulis (2002), Edvardsen and Forsund (2003), Jamasb and Pollitt (2003), Jamasb et al. (2004), Tupper and Resende (2004), Farsi and Filippini (2004) and Giannakis et al. (2005). This section however focuses on studies that use performance measurement to analyse the effectiveness of regulatory mechanisms.

Fraquelli and Vannoni (2000) compare the performance of the main telecommunications operators in France, Germany, UK, Italy and Spain from 1989 to 1993. The results show an improvement in the productivity levels and a reduction in the ratio between output and input prices. While the French and British telecommunications operators were among the most productive, only British Telecommunications was reducing output prices. The authors conclude that incentive regulation has promoted the efficiency of telecommunications operators. They however argue that competition is more effective in reducing the price levels.

Pombo and Taborda (2006) analyse the efficiency of 12 electricity distribution companies in Columbia from 1985 to 2001 to test whether the regulatory reform process enacted in 1994 has a significant impact on efficiency. Their results show that profitability, input and output productivity has improved after the enactment of the regulatory reform. However, they find that efficiency and productivity improved for the largest utilities while the less efficient utilities experienced a degradation in efficiency and productivity. Their second stage regression analysis reveals that ownership does not have a significant impact on performance but regulatory reform has led to an efficiency gain of 5%.

Jamasb et al. (2008) analyse the efficiency and productivity of US gas transmission companies from 1996 to 2004. Surprisingly, they find that cost-plus regulation has been rather successful in promoting productivity and convergence in a period where overall demand was flat. They conclude that in the long-run, market integration and competition promote productivity and efficiency of the gas transmission companies.

Marques and Simoes (2009) analyse the performance of 29 solid waste management companies in Portugal in 2005. The objective of their analysis is to check whether incentive regulation and ownership impact the performance of the waste management companies. They find that ownership has no effect on performance. Surprisingly, they also find that there is no difference in efficiency between the companies, irrespective of whether they are subject to incentive regulation or not.

Li et al. (2017) compare the performance of the ten general electric power utilities in the electrical distribution sector in Japan from 1980 to 2010. Their objective is to analyse whether the regulatory reforms in the electric power industry have had substantial impacts on the performance of the utilities. Interestingly, they find that efficiency levels after the regulatory reforms are lower than those before the regulatory reforms. They argue that cross-subsidization may have caused this drop in efficiency levels. They conclude that Japanese regulators should introduce incentive-based regulatory tools to replace the current rate-of-return regulation.

Soroush et al. (2021) analyse the cost efficiency of 107 economically regulated electricity distribution utilities in Italy from 2011 to 2015. They find that institutional quality is a major factor in promoting the cost efficiency of the regulated utilities. Regions with better responsiveness towards citizens, control of corruption, and rule of law are found to have more cost efficient utilities. They conclude that national regulators should take regional institutional diversity into account in incentive regulation and efficiency benchmarking of utilities.

Another aspect of economic regulation is whether a regulatory agency is independent. Parker and Kirkpatrick (2012) argue that independent regulators do not face the risk of political interference in day to day operations, which can enhance regulatory credibility and commitment. Moreover, dependent regulators may change the operating terms and conditions imposed upon the regulated firms, which can lead to the hold-up problem resulting in under-investment. As a result, they posit that there is a positive correlation between regulatory independence and economic welfare. Studies such as Edwards and Waverman (2006), Cambini and Rondi (2010) and Bortolotti et al. (2011) confirm this hypothesis.

Edwards and Waverman (2006) study the impact of public ownership and independent regulators on the regulated interconnect rates paid by entrants to incumbents in the telecommunications sector in the 15 founding EU member states from 1997 to 2003. They find that public ownership shares in the incumbents has a positive effect on interconnect rates, which suggests that governments influence regulatory outcomes in favour of incumbents in which they have a substantial investment. However, they also find that regulatory independence mitigates this effect. This suggests that independent regulators can counterbalance government ownership shares in a public utility in terms of optimal pricing.

Cambini and Rondi (2010) examine investment and financial decisions of an unbalanced panel dataset of 92 publicly traded utilities and transportation infrastructure operators from the EU 15 founding member states tracked from 1994 to 2005. Their results show that investment increases if regulators are independent while ownership has no effect on investment. Their results also show that leverage increases if regulators are independent especially in the case of privately controlled firms. They also find that investment increases if governments are pro-firm but this effect reverts in case the regulators are independent. They conclude that politics has a weaker impact on financial and investment decisions of firms when regulators are independent because independence disentangles regulatory intervention from political interference.

Bortolotti et al. (2011) analyse an unbalanced panel dataset of 88 publicly traded utilities and transportation infrastructure operators from the EU 15 founding member states tracked from 1994 to 2005 in order to study the effect of the establishment of independent regulators on the market-to-book ratios of these firms. They find that independent regulators along with state ownership positively affects the market value of the regulated firms and high leverage positively affects the market value of private firms. They also find that the positive relation between market value and state ownership is strong in countries where the political institutions do not constrain the power of the executive. They conclude that governments tend to affect the regulatory process in order to benefit state-owned firms, especially in cases where the institutional foundations of regulatory commitment are weak.

We now turn our focus to airport regulation, which is the topic analysed in Chapter 2. Airport regulation has some special features. Airports which are regulated are done so using either a single-till or a dual-till. Under single-till regulation, airport charges are set in anticipation of revenues from both aeronautical and commercial services. Hence, as commercial revenues cover a portion of the airport's fixed costs, airport charges for aeronautical services are reduced accordingly (Czerny, 2006). Hence, with the single-till, all costs are added and charges are then derived. In contrast, dual-till regulation caps only aeronautical revenues in order to set airport charges. Hence, with the dual-till, charges are set to cover aeronautical costs only.

The second unique feature of airport regulation is slot allocation. Slots assign landing and take-off times for airlines that intend to use the airport's facilities. Slots are particularly important at airports with excess demand. Slot allocation should promote the airport to set optimal charges, have the optimal output combination and ensure a higher service quality by lowering congestion and delays.

Chapter 2 focuses on all aspects of airport economic regulation. This chapter reviews the literature on airport regulation and performance in order to arrive at conclusions as to which form of regulation is most preferable to enhance the performance of airports. We find that dual-till price-cap regulation and light-handed regulation are the most preferable from an efficiency perspective. However, we also find that light-handed regulation does not necessarily lead to the cheapest airports. After reviewing the literature, we also give suggestions for future research. We identify aspects from the theory which have not yet been sufficiently analysed in the empirical literature.

With respect to seaports, there are a few studies that measure the effectiveness of regulatory mechanisms by employing benchmarking models. Cullinane et al. (2002) analyse the technical efficiency of 15 Asian container ports or terminals from 1989 to 1998. They find that privatization and deregulation positively impact the technical efficiency of the ports or terminals. Moreover, Cullinane and Song (2003) analyse the technical efficiency of two Korean and three British container terminals from 1978 to 1996. They find that a higher degree of privatization and deregulation leads to higher technical efficiency. They suggest that higher privatization with the promotion of higher competition will lead to a higher technical efficiency among container terminals. Rodriguez-Alvarez et al. (2007) study the technical and allocative efficiency of three port terminals located in the Las Palmas port in Spain from 1991 to 1999. They find that labour-related regulations negatively affect allocative efficiency limiting the terminal operators' flexibility.

We contribute to the literature by performing a more in-depth analysis of how regulation can impact the technical efficiency of seaports. In Chapter 3, we analyse how rate-of-return regulation by an independent regulator impacts the technical efficiency of major Indian seaports. We find that regulation by an independent regulator is more conducive to technical efficiency of the major Indian seaports in comparison to internal regulation by the port authority. As the independent regulator is not susceptible to regulatory capture unlike the port authorities, rate-of-return regulation by an independent regulator is preferred to internal regulation by the port authority. In Chapter 4, we analyse the relation between institutional regulation and technical efficiency of container ports in the Far East and Asian region. As container ports in Asia can be regulated by a government ministry, port authority, an independent regulator or have no regulation, we analyse how rate-of-return regulation by various institutions affects the technical efficiency of these container ports. From the individual and the combined effects models, we find that regulation by an independent regulator is the most conducive to technical efficiency of these container ports. We propose the setting up of independent regulators for the regulation of the container ports from the Far East and Asian region, which can be beneficial as it enhances technical efficiency of these container ports.

1.2. Benchmarking Techniques

As this thesis focuses on the relation between governance and performance of airports and seaports, it is of interest to outline the methodologies which are used to measure the performance of these firms. In analysing the performance of airports and seaports, it is useful to distinguish between productivity and efficiency. Productivity can be defined as the ratio of an aggregate measure of outputs to an aggregate measure of inputs. A firm which is technically efficient need not exhibit the maximum possible productivity. In order to achieve this, the technically efficient firm may have to move to another point on the production frontier which is the point of optimal scale. As a result, a technically efficient firm may be able to enhance its productivity by exploiting scale economies. Another source of productivity change over time is technical change. Consequently, improvement in productivity can be attributed to efficiency improvements, exploitation of scale economies and technical change (Coelli et al., 2005, pp. 2-6).

In analysing the efficiency of airports and seaports, it is worthwhile differentiating between technical, cost and allocative efficiency. A firm is technically efficient if it is able to produce the maximum output given its set of inputs or if it is able to produce a given level of output utilizing the minimum set of inputs while still remaining within the feasible production set. A firm is cost efficient if it produces a particular output at minimum cost given the input prices it faces. Input oriented allocative efficiency is the firm's ability to select the correct mix of input quantities such that the input price ratios equal the ratios of the corresponding marginal products. Output oriented allocative efficiency is the firm's ability to select the combination of output quantities such that the ratio of output prices equals the ratio of marginal costs (Coelli et al., 2003, pp. 11-12).

It is also useful to analyse the scale efficiency of airports and seaports. A firm which exhibits technical and allocative efficiency may not be operating at the optimal scale. Suppose that a firm is using a variable returns-to-scale technology, it may be too small operating with increasing returns-to-scale meaning that a doubling of the inputs more than doubles the output in which case it is optimal for the firm to increase its capacity. On the other hand, the firm may be too large operating with decreasing returns-to-scale meaning that a doubling of the inputs less than doubles the outputs in which case it is optimal for the firm to scale down its operations. In both of these cases, it is optimal for the firm to utilize the same input mix but change the size of its operations. On the other hand, a firm which exhibits technical and allocative efficiency and operates with constant returns-to-scale globally can be automatically deemed scale efficient (Coelli et al., 2005, pp. 58-61).

In this section, we discuss the methodologies that are used to measure airport productivity and efficiency. We first discuss total factor productivity (TFP), followed by the two frontier approaches namely stochastic frontier analysis (SFA) based on regression and data envelopment analysis (DEA) based on mathematical programs.

1.2.1. Total Factor Productivity

TFP is the ratio of aggregate output produced relative to aggregate input used when a firm makes use of multiple inputs and outputs. TFP change can be defined as the comparison of outputs produced in two periods with the maximum level of outputs utilizing given inputs operating under the reference technology. TFP is an aggregate productivity measure which can be estimated in several ways including parametric approaches, assuming production functions and non-parametric index number approaches. In making index number based TFP computations, it is assumed that a firm exhibits technical and allocative efficiency. In order to make comparisons between many firms, index numbers are derived such that they are transitive (Coelli et al., 2005, pp. 61-123).

We discuss the index number approach proposed by O'Donnell (2012b). This is called the Hicks-Moorsteen TFP index which is a multiplicative index formulated as the ratio of Malmquist output and input quantity indices. The advantage of this index is that it requires only information on quantity, does not require any assumptions to be made with respect to a firm's returns-to-scale and behaviour and does not assume a specific production function. Another advantage of this index number approach is that the derived measure of TFP can be disaggregated into multiple components such as technical change and measures of efficiency change including technical efficiency, scale efficiency, mix efficiency and residual scale efficiency.

1.2.2. Stochastic Frontier Analysis

Estimation of the production function of a given output and the efficiency with which each firm operates is of interest to study and improve performance at the firm and aggregate levels, in addition to the implementation of economic regulation. A popular framework for carrying out such estimation is the SFA model, in which the output is composed of three terms. The first term estimates the underlying production function, which expresses the relationship between the inputs and the outputs. The second term is a random effect term, asymmetrically distributed, which reflects the efficiency of the individual firm. The third term is a random error component, typically assumed to be symmetrically distributed, which accounts for the combined effects of various types of errors such as the inadvertent omission of relevant variables from the production function, errors of measurement in inputs and approximation errors.

Aigner et al. (1977) and Meeusen and van den Broeck (1977) introduced the concept of a stochastic frontier, aimed at incorporating producer-specific random shocks into the analysis. In SFA, the output is modelled such that the stochastic production frontier consists of two parts; a deterministic production function common to all producers and a producer-specific part which captures the effect of random shocks experienced by the producer. We subsequently obtain the production frontier and the technical efficiency with the assumption that technical efficiency takes a value below one and that the random effect term has a value greater than or equal to zero. The random effect term and the random error component are independent and identically distributed across the firms and the noise component is assumed to be symmetrically distributed and independent of the random effect term. Consequently, the error term is asymmetric, since the random effect term is greater than or equal to zero. Another standard assumption is that the random effect term and the random error component are independent of the inputs. Parametric forms are assumed for the random effect term and the random error component. Distributions commonly used for the random effect term include the half-normal, truncated normal, exponential and gamma. Usually it is assumed that the random error component has a normal distribution.

Early papers on the SFA model assumed that the production function is a log-linear Cobb-Douglas (1928) function. More recent papers often assume that the production function follows the translog function. Of all the flexible forms, the translog functional form is the most frequently used because it provides a second order approximation to any structure and allows a large variety of substitution patterns. Regularity conditions are imposed by linear restrictions to the parameters. Recent papers have also made use of distance functions due to many of the desirable properties. The stochastic directional distance function permits an analysis of multiple inputs and multiple outputs simultaneously (Coelli and Perelman, 2000). Cost efficiency can also be estimated with stochastic frontier analysis. Along with the outputs, estimation of a cost frontier also requires information on the vector of input prices.

1.2.3. Data Envelopment Analysis

DEA is a non-parametric method of frontier estimation that measures the relative efficiency of firms, often denoted as decision-making units, utilizing multiple inputs and outputs. DEA accounts for multiple objectives simultaneously without attaching ex-ante weights to each indicator and compares each decision-making unit (DMU) to the efficient set of observations, with similar input and output ratios, assuming neither a specific functional form for the production function nor the inefficiency distribution. DEA was first published in Charnes et al. (1978) under the assumption of constant returns-to-scale and was extended by Banker et al. (1984) to include variable returns-to-scale. This non-parametric approach solves a linear program per DMU and the weights assigned to each linear aggregation are the decision variables of the mathematical program. The weights are chosen optimally in order to show the specific DMU in as positive a light as possible, under the restriction that no other DMU is more than 100% efficient with the same set of weights. This approach allows each firm to set its own priorities, whether input minimizing given the outputs to be served or output maximizing given a set of inputs available. Consequently, a Pareto frontier is estimated, marked by specific DMUs on the boundary envelope of input-output variable space. With DEA, we obtain a relative efficiency score, where a value of one indicates efficiency and a value smaller than one in an input oriented DEA model indicates the level by which the relevant inputs ought to be decreased in order for a DMU to be deemed relatively efficient. Either the input or the output orientation may be considered reasonable when benchmarking airports and seaports depending on the long-run or short-run nature of the analysis. In addition, non-oriented models may also be used, in which case firms simultaneously minimize inputs and maximize outputs in determining the efficiency scores.

1.3. Concluding Remarks

There is a substantial amount of empirical research on the performance impact of ownership, competition and economic regulation. With respect to ownership, there is no consensus about whether public or private ownership is more conducive to enhanced performance. The analysis becomes further interesting because many firms operate with public-private partnership agreements and it is of interest to analyse whether such firms are operating efficiently or not.

In the case of competition, a majority of the applied research shows that competition enhances performance. This may however not be the case when there is excessive entry, when the industry is a natural monopoly, when there is the empty core problem, and when there is destructive competition. Excessive entry may lead to the business-stealing effect which can harm efficiency. When the industry is a natural monopoly, it may be desirable to have only one supplier who can provide the output at lower costs. As firms may not be able to recover full costs due to the empty core problem, potential investors may not make new investments which will lead to a suboptimally low capacity and this can harm efficiency. Destructive competition may lead to many producers exiting the market because they are not able to recover costs or make profits and this can also harm efficiency. It is hence of interest to analyse how competition affects the performance of seaports.

There has been quite substantial regulatory reform in public utilities over the past few decades. Firms are increasingly being subject to incentive and light-handed regulation as opposed to rate-of-return regulation, which used to be the norm before the reforms were introduced. Moreover, regulators are becoming autonomous, which is argued to enhance performance. It is thus of interest to study how regulatory reform impacts the performance of airports and seaports.

TFP, SFA and DEA are the most commonly applied tools to study productivity and efficiency. Because these methodologies can be used to study overall performance of firms as opposed to partial performance indicators, which can only study a part of the performance of firms, research has been increasingly applying methods such as TFP, DEA and SFA to analyse the performance of firms.

This thesis studies how governance impacts the performance of seaports and airports. Chapter 2 focuses on how regulation impacts the performance of airports. A literature review is conducted, which analyses studies that use TFP, SFA and DEA, in order to link regulation and regulatory reform to the performance of airports. In Chapter 2, we also propose avenues for future research based on the evidence. We study the theoretical and empirical literature and find gaps in the empirical literature, which require further analysis. Chapter 3 analyses how governance impacts the performance of major Indian seaports. We apply a non-oriented slacks based measure (SBM) in the first stage and fixed effects regression in the second stage in order to link governance-related factors to the technical efficiency of the major Indian seaports. Chapter 4 analyses the impact of the governance-related factors identified in this chapter on the technical efficiency of container ports in the Far East and Asian region. This chapter uses SFA in order to estimate a production frontier. It employs a single step procedure that can be used to estimate the production frontier as well as to estimate the impact of the governance-related factors on the technical efficiency of these container ports. We estimate individual as well as combined effects of the contextual variables on the technical efficiency of these container ports, which gives further insights on how governance can impact technical efficiency.

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Chapter 2

Does regulation improve efficiency? The case of airports[1]

Abstract

This paper reviews the methods applied to regulate airports and their impact on efficiency. Our review reveals that different market structures and regulatory environments have varying impacts on efficiency. The majority of studies find that airport regulation has proven to encourage technical, financial and cost efficiency, however a few find negligible to negative impact on efficiency levels. We find that dual-till incentive regulation is more effective in promoting airport efficiency in comparison to rate-of-return regulation. We also find that light-handed regulation leads to efficient airports but does not necessarily result in the cheapest airports in terms of aeronautical charges. Finally, we find that many aspects of airport regulation and efficiency have not been assessed and require further research.

Keywords**:** efficiency, benchmarking, performance, regulation, data envelopment analysis, stochastic frontier analysis, total factor productivity, market structure

2.1. Introduction

Regulation of public utilities including airports might be welfare enhancing if regulation corrects market failure due to natural monopoly because the airport with significant market power could restrict output, charge a higher price and lack of managerial incentives could lead to managerial slack (Armstrong et al., 1994; Sherman, 1989; Leibenstein, 1966). Economic regulation is argued to increase efficiency, service quality, social welfare and reduce prices in such cases. Market failure does not automatically mean that regulation is necessary because economic regulation is itself expensive and there should be a cost-benefit analysis of whether economic regulation of an airport is necessary and economic regulation should be imposed on airports with significant market power only if it creates net benefits. As a result, economic regulation of airports should be assessed in terms of economic welfare, which is the focus of this paper. In practice, airports today have begun to privatize with a profit maximization objective and thus remain subject to economic regulation (Gillen, 2011; Adler et al., 2015).

Historically, airports were regulated using rate-of-return regulation. Rate-of-return regulation involves setting price levels by defining an asset rate base and the maximum rate of return that the firm may earn on those assets (Sherman, 1989, p. 189). This form of regulation is implemented in Brussels, Amsterdam, Zurich and at all major German airports (Forsyth et al., 2021). Because rate-of-return regulation might not necessarily be welfare maximizing due to some drawbacks, economists have reformed regulation by developing incentive regulation so that regulation maximizes welfare and efficiency. The most prominent form of incentive regulation is RPI-X price-cap regulation where the average growth rate of prices is limited to the growth rate of the retail price index minus an X term which accounts for the expected efficiency improvement of the firm over time among other factors. As profits are not regulated, all cost reductions will lead to a higher profit to the regulated firm which it is allowed to retain (Armstrong et al., 1994, p. 167). Incentive regulation is implemented in Vienna, Budapest,

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Dublin, London Heathrow and at all major French and Italian airports (Forsyth et al., 2021). Regulatory reform has also developed another form of airport regulation namely light-handed regulation. Light-handed regulation involves the monitoring and review of airport charges, costs, profits and quality of service. Although prices are not regulated, explicit price regulation could be re-introduced if the regulatory review concludes that the airport is abusing its market power (Forsyth, 2008). Light-handed regulation is implemented in Copenhagen, Gatwick and at airports in Australia and New Zealand (Forsyth et al., 2021; Forsyth, 2008). There are a significant number of airports that have switched from rate-of-return regulation to incentive and light-handed regulation. Airport regulation has also experienced institutional reform because there has been a move towards independent regulators in order to avoid conflict of interests and regulatory capture. This paper aims to analyse whether airport regulatory reform has worked in improving efficiency and enhancing welfare.

With respect to efficiency, the role of airport regulation is to promote technical, cost and allocative efficiency. Three well-documented quantitative methods have been frequently applied to analyse the productivity and efficiency of government and private enterprises. An index number approach estimates total factor productivity (TFP) (Caves et al., 1982; Hooper and Hensher, 1997; Oum and Yu, 2004; Vasigh and Gorjidooz, 2006). Parametric stochastic frontier analysis (SFA) assesses efficiency utilizing econometrics (Aigner et al., 1977; Meeusen and van den Broeck, 1977; Pels et al., 2003; Oum et al., 2008). Non-parametric data envelopment analysis (DEA), based on linear programming, categorizes observations into efficient and inefficient groups. Airport studies of efficiency utilizing all three approaches are reviewed in Liebert and Niemeier (2010).

The objective of this paper is to review the impact of regulation on the efficiency of airports, because, as we argued above, regulation has been reformed in many cases towards incentive and light-handed regulation over the last 30 years and these reforms need to be assessed in terms of economic efficiency. Moreover, the impact of such regulatory reforms seem to be more important than the influence of privatization. Our review reveals that a majority of the studies find that airport regulation has a positive impact on efficiency. Moreover, incentive and light-handed regulation positively impact efficiency and dual-till regulation is the most effective form of regulation. Previous reviews such as Liebert and Niemeier (2010) have a broader focus and have not assessed airport regulation and its efficiency impacts in detail. Our paper contributes to the literature by assessing airport regulation and its efficiency impacts in detail through a literature survey of the studies on this topic. In addition, we also review the papers that analyse the impact of airport regulation on charges. The rest of the paper is organized as follows: Section 2.2 analyses airport regulatory reform from a historical perspective; Section 2.3 describes the three main methods used for estimating airport performance; Section 2.4 reviews the literature that assesses the impact of regulation on airport performance; Section 2.5 concludes based on the literature to date and we also discuss the remaining disagreements and potential ways forward in this section.

2.2. Airport Regulatory Reform

This section focuses on the regulatory reform of airports over time. We first provide an overview of regulatory reform in general and describe how this was imposed upon airports. We then focus on the special features of airport regulation namely single-till versus dual-till and slot allocation. We finally summarize the expected effects of airport regulation on efficiency.

2.2.1. Regulatory Reform – A General Perspective and Evolution of Airport Regulation

Rate-of-return regulation was developed in the US which focused on the conduct of franchised private monopolies. With rate-of-return regulation, an asset base is defined and the regulated firm is allowed to earn a certain rate-of-return on the defined asset base. As a result of this regulatory mechanism, what we obtain is the price level that the firm is allowed to charge in order to receive the required rate-of-return on the defined asset base (Sherman, 1989, p. 189).

Historically, airports were regarded as public utilities of national importance and governments supported and subsidized investment and operation. Cost recovery was key and that included a normal rate of return. Charges were based on book keeping costs and the opportunity cost principle was not applied (Doganis, 1992). In fact, ICAO (2012) prescribes policies on charges for airports wherein it states that airports should charge aircraft operators and other airport users, including end-users, such that the full cost of providing the airport and its essential ancillary services is recovered. As a result, ICAO prescribes a cost-based pricing mechanism. Public airports were often internally regulated by the state using this cost-based pricing mechanism. Thereafter, public airports were privatized or commercialized, both of which called for regulation. In either case, the tendency has been to use cost-based regulation (Gillen and Niemeier, 2008) as has been strongly recommended by ICAO.

Although rate-of-return regulation restricts a firm from abusing its market power by preventing it from following monopoly pricing, it is argued to have some drawbacks and can lead to cost inefficiency, overcapitalization, financial inefficiency and high administrative costs (Liston, 1993). Cost inefficiency is caused because a firm with higher costs earns a higher rate-of-return hence a firm facing rate-of-return regulation might resort to cost padding because there is little incentive to be cost efficient. In addition, overcapitalization was first described as the Averch and Johnson (1962) effect. A firm earns a rate-of-return on the capital employed. When this rate-of-return is higher than the cost of capital, the firm has an incentive to substitute capital for other factor inputs. This leads to an excessively high capital level employed such that the factor input levels and output level is not cost minimizing. As a result, price control leads to a misallocation of factor inputs that does not result in cost minimization. Financial inefficiency may be caused due to a suboptimal debt-equity ratio. Moreover, this form of regulation leads to high administrative costs due to the amount of information required for the valuation of the asset base and the forecasting of costs and demand (Armstrong et al., 1994, p. 167).

Regulatory reform has focused on addressing the shortcomings of rate-of-return regulation discussed above. The most prominent form of regulation that has emerged is incentive based price-cap regulation. This form of regulation fixes a firm's price path over time and as a firm's price level is not related to costs, the firm has an incentive to minimize its costs. This is because there is no downward revision in price if the firm is able to cut costs which means that the firm retains the profits earned by being cost efficient. One form of price-cap regulation is known as RPI-X regulation where some of the gains from cost efficiency are passed on to consumers when the price-caps are reviewed. The prices are adjusted in accordance with an increase in the retail price index (RPI) minus the X term which accounts for the productivity gains of the firm. As a result, real prices decrease over time which ensures that some of the gains from the firm's cost efficiency are passed onto the consumers (Cowan, 2002).

Beesley and Littlechild (1989) have compared incentives and efficiency motives that exist under rate-of-return regulation and RPI-X regulation. They argue that even though both forms have similar features, RPI-X regulation has some potential advantages over rate-of-return regulation with regards to incentives and efficiency motives for the firm being regulated. RPI-X has an exogenous risk period, it is a forward looking approach, the regulator has more degrees of freedom and the regulator has less requirement to explain. As a result of these four differences, with RPI-X regulation, the regulator has a stronger bargaining power in setting the level of X which results in incentives and efficiency motives for the firm being regulated.

Another important issue and advantage of RPI-X regulation over rate-of-return regulation is that price-cap regulation regulates only the price level and not the price structure. Rate-of-return regulation and cost-based regulation set incentives for rather uniform price structures. They do not set incentives for peak and off-peak pricing although the demand for many public utilities fluctuate and has such patterns. Price-cap regulation sets incentives to rebalance the price structure in order to increase the profits. It can thus incentivize Ramsey pricing and peak pricing (Bradley and Price, 1988; Knieps, 2008) although the results for public utilities are rather mixed (Giulietti and Waddams Price, 2005).

Airport price-cap regulation was first introduced in the UK in 1986 for the airports owned by BAA as they were considered to have significant market power. Over time the number of regulated airports in the UK has been reduced from four to two airports. Following the introduction of RPI-X price-cap regulation for the airports in the UK, airports from all around the world including those in Australia, Austria, France, Germany, Hungary, Italy, India, Ireland, Portugal and South Africa have implemented price-cap regulation in some form or the other (Forsyth, 2008; Gillen and Niemeier, 2008; Niemeier, 2009). Adler et al. (2015) distinguish between whether the price-caps are high, medium or low powered. They argue that pure price-caps as has been applied in Malta and Australia provide the airports a strong incentive to be cost efficient as the price-caps are not related to costs. Hybrid price-caps as have been applied outside of the UK at some Italian, Irish and French airports are argued to have medium powered cost efficiency incentives. These authors argue that traffic risk sharing mechanisms are low powered as they do not provide incentives to effectively manage capacity in periods of excess demand. Such traffic risk sharing mechanisms have been implemented at Austrian, French and German airports. Price-cap regulation as has been applied at some Indian airports is also argued to be low powered because the price-caps are based on costs and the regulator sets the price structure as well.

The disadvantages of price-cap regulation are that it could lead to a lower quality of service, informational asymmetries could lead to high price-caps, the firm is not incentivized to serve all classes of customers and the lack of rate hearings deprives consumers from expressing their preferences (Liston, 1993). The literature on RPI-X regulation has discussed potential solutions to overcome the disadvantages of this regulatory mechanism with special attention paid to the underinvestment problem. Helm (2009) states that the time inconsistency problem might result in the regulator taking undue advantage of the regulated firm by lowering charges once the investment is sunk. As the regulated firm might be aware of the regulator's intention to reduce prices to marginal cost after the investment is completed, the regulated firm will have no incentive to invest in new capacity leading to underinvestment and low service quality. He reviews the concept of a regulated asset base (RAB) which comprises of assets necessary for the firm to operate. He suggests that a portion of the costs contained in the RAB, which also consists of new investments, could be passed-through to consumers. This would in turn incentivize the regulated firm to undertake new investments resulting in adequate investment. As another outcome of price-cap regulation could be low service quality, quality monitoring is often applied along with price-cap regulation to ensure adequate service quality.

Another outcome of regulatory reform is light-handed regulation or monitoring. Explicit economic regulation has a cost even though it may be worthwhile. These are costs related to technical and cost efficiency as well as costs to avoid prices from being too high, which is related to allocative efficiency. As a result, light-handed regulation could be used in order to reduce the negative effects of explicit economic regulation on technical, cost and allocative efficiency. With light-handed regulation, there is no explicit economic regulation but instead the regulatory institution closely monitors the conduct of the regulated utility and intervenes in case there is an abuse of market power by the regulated utility. Another feature of this form of regulation is that agreement between the producer and customer on price and quality of service are reached through negotiated settlements with supervision by the regulator (Schultz, 1999; Doucet and Littlechild, 2006). King and Maddock (1999) build a negotiate-arbitrate model which shows that the access seeker and provider reach an agreement at the negotiation phase provided that the outside option of regulatory arbitration is available to both parties. Their equilibrium is characterized by a lower price which leads to efficiency gains due to the possibility of regulatory intervention. Moreover, Cowan (2007) presents a model which shows that light-handed regulation can generate a higher welfare in comparison to both rate-of-return and price-cap regulation.

The advantages of light-handed regulation over explicit economic regulation are that it reduces the cost of regulation; it reduces the information supply costs imposed on the regulated utility and reduces the scope for the regulated firm to engage in opportunistic behaviour; it avoids the compliance costs arising from imperfect regulation; it avoids the losses associated with possible corruption and regulatory capture; and it avoids the dynamic losses associated with the control by regulators of industry structure and conduct, which may inhibit new entry, competition and innovation (Bollard and Pickford, 1995).

Recent airport regulatory reform has been introduced in the form of light-handed regulation. This form of regulation was first introduced for the major Australian airports in 2002 after a period of price-cap regulation which was previously applied after the privatization of these airports (Forsyth, 2002, 2004, 2008). In reviewing light-handed regulation of airports in Australia and New Zealand, Forsyth (2008) highlights two disadvantages of such an approach to regulation. The first disadvantage concerns the effectiveness of the review/sanction approach which might be weak in limiting the airports from using their market power. The second disadvantage is that light-handed regulation might degenerate into a form of cost-plus regulation if the regulator's objective is to keep prices close to cost. This might lead to excessive investments, higher prices and lower efficiency as is the case with cost-plus regulation.

Forsyth (2008) and Littlechild (2012) propose a negotiate-arbitrate model to solve the potential shortcomings of light handed airport regulation. With such a mechanism in place, it could be argued that the stakeholders would reach an agreement in most cases prior to referring to the regulator. This could result in lower charges, optimal investment, higher efficiency, higher service quality and a lower amount of time required in order for the stakeholders to reach a settlement in the case of disputes.

Utility privatization is often accompanied by the introduction of specialist regulatory institutions. The role of these specialist regulatory institutions is to protect consumers by preventing the natural monopoly from abusing its market power on the one hand and to protect investors from unacceptable risks on the other. Two features needed in order to introduce good regulatory institutions are that they should be independent from government intervention (Winsor, 2010) and they should not be susceptible to regulatory capture from the regulated utilities. Independence from government intervention is needed because governments either tend to hold prices down below marginal costs (Stern, 1997) or because the government is in many cases a shareholder of the regulated enterprise (OECD/ITF, 2011). Independence from the regulated utilities is needed in order to prevent the utilities from gaining favourable terms of trade to the detriment of consumers and competitors. Biggar (forthcoming) applies a transaction costs approach to argue that the role of the public utility regulator is to protect the sunk investments of consumers of a natural monopoly. In this case, for a government owned natural monopoly, an independent regulator could help improve the efficiency and performance of the government owned enterprise and make regulatory decisions in a neutral and objective manner. In the case of a privately owned utility, the independent regulator would act as a neutral arbiter between the interests of the consumers and the interests of the owner. In either case, an independent regulator would be in a better position to protect the sunk investments of the consumers.

In the case of airports, there are three distinct models for regulatory institutions. In the first model, the regulator is part of the government that has no ownership share in the regulated airports. This model has been adopted in Austria and was also used in Hungary until Budapest airport was fully privatized. In the second model the regulator is independent of the government as well as the regulated airport and is thus fully independent and is controlled by the parliament. This model for airport regulators is practised in UK, Ireland, Italy and Australia. The third model is one where the airport regulator is a part of the government, which has an ownership share in the regulated airport. In this case, the airport has independence neither from the government nor from the regulated utility. This is the case in Belgium, Germany and Spain and the airlines fear regulatory capture in this case (Forsyth et al., 2021). In relation to the third model, Niemeier (2010) argues that ownership and regulation of monopolistic bottlenecks need to be separated. He argues that a dependent regulator opens the door to regulatory capture, raises barriers to private investment, weakens the incentive for cost and allocative efficiency and prevents the spreading of competition.

2.2.2. Special Features of Airport Regulation

Airports which are regulated are done so using either a single-till or a dual-till. Under single-till regulation, airport charges are set in anticipation of revenues from both aeronautical and commercial services. Hence, as commercial revenues cover a portion of the airport's fixed costs, airport charges for aeronautical services are reduced accordingly (Czerny, 2006). Hence, with the single-till, all costs are added and charges are then derived. In contrast, dual-till regulation caps only aeronautical revenues in order to set airport charges. Hence, with the dual-till, charges are set to cover aeronautical costs only.

Niemeier (2021) differentiates between old and new approaches that analyse the efficiency and welfare implications of imposing a single- or a dual-till. According to the old stream of literature, single-till is preferable at a non-congested airport as the airport could set aeronautical charges at marginal cost and the resulting deficit could be covered by the commercial revenues that it earns. Nevertheless, there are strong arguments that favour the dual-till at non-congested airports. First, the airport could use Ramsey pricing for aeronautical charges in order to eliminate the deficits. Second, subjecting the airport to single-till might lead to opportunistic behaviour by the regulator. At a congested airport, a dual-till encourages peak and off-peak pricing while the single-till distorts competition and leads to a higher scarcity rent for airlines. As a result, a dual-till is preferred to a single-till at a congested airport. So as per Niemeier's (2021) review of the old stream of literature, a dual-till is preferred to a single-till regardless of whether an airport is congested or not.

The results from the new stream of literature suggest that the efficiency and welfare implications of imposing either a single-till or a dual-till seem to be a function mainly of whether an airport is congested or not. Czerny (2006) compares single-till and dual-till price-cap regulation and their welfare implications. He assumes that the airport is not congested and his results show that single-till price-cap regulation dominates dual-till price-cap regulation from a welfare perspective. Yang and Zhang (2011) make a welfare comparison of single-till and dual-till price-cap regulation at congested airports. They show that at congested airports, dual-till price-caps lead to a higher welfare than single-till price-caps. The results from the new stream of literature seem to suggest that single-till is preferable when there is no congestion and dual-till is preferable from an efficiency and a welfare perspective when there is airport congestion.

The debate on single-till and dual-till has also been analysed from other perspectives. For example, Malavolti (2016) models an airport as a two-sided market and finds that a single-till is preferable to a dual-till because a single-till is able to take into account the externalities that exist between the commercial and aeronautical activities. Moreover, Czerny et al. (2016) compare the two different forms and show that market power is better controlled and cost recovery is better promoted with single-till regulation while dual-till regulation is shown to better handle congestion and in promoting airport investment. From a distributional perspective, lower charges mean that airlines benefit more from single-till regulation while the higher charges mean that airports benefit more from dual-till regulation. So despite the fact that a single-till leads to a lower charge in comparison to a dual-till, in addition to congestion, the efficiency and welfare analyses will have to take factors such as the type of regulation (rate-of-return or price-cap), market power, cost recovery, investment, rent distribution and externalities into account in order to arrive at conclusions as to which form is more preferable.

The second unique feature of airport regulation is slot allocation. Slots assign landing and take-off times for airlines that intend to use the airport's facilities. Slots are particularly important at airports with excess demand. Slot allocation should promote the airport to set optimal charges, have the optimal output combination and ensure a higher service quality by lowering congestion and delays. Forsyth and Niemeier (2008a) compare slot capacity systems and congestion rationing and find that an effective slot capacity system is superior to a congestion rationing system in promoting allocative efficiency. Forsyth and Niemeier (2008b) analyse slot capacity systems and pricing and their linkage to regulation and allocative efficiency. They argue that slot constrained airports should have uniform peak prices in order to encourage runway utilization by larger aircraft instead of smaller aircraft. They argue that uniform peak pricing with slot constraints can be used to ration demand that results in high allocative efficiency. With regards to the type of regulation, they argue that rate-of-return regulation would give the airport no incentive to pursue peak pricing and they show that a desirable price structure is adopted by the airport when there is price-cap regulation.

In the EU, slot allocation is done administratively, with highly congested airports being slot coordinated and airports facing potential congestion being schedules facilitated. Moreover, in the EU, slot allocation follows the grandfathering principle wherein incumbent airlines retain their share of slots in the next period provided that they have used at least 80% of the slots in the previous period and 50% of the unallocated slots are thereafter reserved for new entrants. Economists (see Czerny et al., 2008; Guiomard, 2018; Adler and Yazhemsky, 2018) have been critical of these rules and the EU Commission has tried to reform these rules, but has so far failed (on the political economy see Forsyth and Niemeier, forthcoming). Guiomard (2018) argues that administrative slot allocation, as has been applied in the EU, leads to allocative inefficiency and has anti-competitive effects (see also NERA, 2004). He argues that allocative inefficiency is caused due to the absence of prices which leads to airlines neglecting the opportunity cost of slot use. Moreover, absence of slot prices would also hamper investment in capacity when needed (Ewers, 2001; on the political economy see also Gillen and Starkie, 2016). With regards to competition, he argues that administrative slot allocation favours incumbents at the expense of new entrants with incumbent airlines enjoying a higher scarcity premium resulting from higher air ticket prices. At airports where demand exceeds supply, he proposes that secondary slot trading, higher runway charges and slot auctions would promote higher output oriented allocative efficiency as these instruments are based on economic principles rather than on administrative principles (on slot auctions see Pertuiset and Santos, 2014).

2.2.3. Expected Effects of Airport Regulation on Efficiency

Table 2.1 summarizes the discussion so far and gives an overview of the different market structures and regulatory environments and their likely impact on efficiency (see Section 2.3 below for the definitions of the different concepts of airport efficiency). Under monopolistic conditions, firms generally seek to maximize their profits by limiting output and increasing prices, hence economies of scale may not be fully exploited which has a negative impact on technical and cost efficiency. However, this is not the case with airports which are not private and they may not maximize profits. In addition, monopolies might fail to produce with cost efficiency due to managerial slack leading to Leibenstein X-inefficiency. As a result, a natural monopoly should be subject to economic regulation. On the other hand, in a potentially competitive environment, regulation may not be desirable as it could distort technical and cost efficiency.

With regards to regulation, rate-of-return regulation is expected to lower the charges and increase output in comparison to an unregulated monopolistic market which enhances technical and cost efficiency. However, as the airport subject to rate-of-return regulation earns a pre-specified rate-of-return on the capital employed, the positive effect on technical and cost efficiency might be reduced and even overcompensated by overinvestment, as described by Averch and Johnson (1962). In addition, gold plating and cost padding have a negative impact on cost efficiency. At congested airports, rate-of-return regulation provides little incentive to pursue peak pricing, which has a negative impact on output oriented allocative efficiency, which is not the case with incentive regulation. It should however be noted that peak pricing for runways only makes sense for the US airports since slots ration demand in other cases. Incentive regulation should encourage higher allocative efficiency and improved cost efficiency but may also lead to under-investment and deterioration in the quality of service, which might negatively impact technical efficiency. At airports with excess supply, incentive regulation promotes Ramsey pricing in the form of weight-based charges because the price structure remains at the discretion of the airports which is not the case with rate-of-return regulation. As a result, at airports with excess supply, by promoting Ramsey pricing, incentive regulation facilitates higher technical, cost and allocative efficiency.

Market Structure/ Regulatory Environment	**Description**	**Impact on Efficiency**
Monopoly	Restriction of output and unexploited economies of scale	Negative impact on technical and cost efficiency
	Leads to *X*-inefficiency	Negative impact on cost efficiency
Competitive Market	Regulated airports may distort efficiency	Negative impact on technical and cost efficiency
Rate-of-Return Regulation	Lower charges increase output in comparison to monopolist	Positive impact on technical and cost efficiency
	Congested airports have no incentive to set peak prices	Negative impact on allocative efficiency
	Averch-Johnson effect, gold plating and cost padding	Negative impact on cost efficiency
Single-Till Rate-of-Return Regulation	Restricts potentially competitive commercial activities	Negative impact on technical efficiency
Dual-Till Rate-of-Return Regulation	Higher charges decrease output in comparison to single-till rate-of-return regulation	Negative impact on technical and cost efficiency
Price-Cap Regulation	Peak pricing promotes allocative efficiency	Positive impact on allocative efficiency
	Encourages cost efficiency	Positive impact on cost efficiency
	Under-investment leads to deterioration in quality of service	Negative impact on technical efficiency
Single-Till Price-Cap Regulation	Leads ceteris paribus to lower caps compared to dual-till	Positive impact on technical and cost efficiency
	Creates weak incentives to earn commercial revenues	Negative impact on technical efficiency
Dual-Till Price-Cap Regulation	Encourages airports to lower aeronautical charges thus increase passenger throughput, but ceteris paribus less than single-till	Positive impact on technical efficiency

Market Structure/ Regulatory Environment	Description	Impact on Efficiency
	Commercial revenues are unrestricted	Positive impact on technical efficiency
Light-Handed Regulation	With credible threat and an arbitration mechanism, encourages cost efficiency and output oriented allocative efficiency	Positive impact on cost and allocative efficiency
	Flexible with a low amount of regulatory burden	Positive impact on cost efficiency
	A congested airport has the incentive to practice peak pricing and an airport with excess capacity has the incentive to pursue Ramsey pricing	Positive impact on allocative efficiency
Independent Regulator	Provides long term commitment for immobile and specialized investment	Positive impact on cost and allocative efficiency
	Prevents charges from increasing above the optimal level and also encourages airports not to increase costs above the optimal level	Positive impact on cost efficiency

Table 2.1: Market structure, regulatory environment and impact on efficiency

With regards to the approach to regulation, single-till rate-of-return regulation leads to lower charges and higher output in comparison to dual-till rate-of-return regulation, which has a positive impact on technical and cost efficiency. However, as the single-till approach taxes commercial revenues, the airports will have little incentive to be innovative and search for alternative commercial revenues. This in turn has a negative impact on technical efficiency. In contrast, the dual-till approach regulates aeronautical revenues alone in order to constrain only those activities with a monopolistic server. As a result, with dual-till regulation, airport management are incentivised to innovate thus earn higher non-aeronautical revenues which are unconstrained leading to a positive impact on technical efficiency.

With respect to light-handed regulation, a congested airport can behave in a profit maximizing manner and practice peak pricing. An airport with excess capacity also has the incentive to pursue Ramsey pricing as the price structure is not explicitly regulated. These attributes of light-handed regulation maximize allocative efficiency. Moreover, light-handed regulation is more flexible, involving lower regulatory burden which may be effective in promoting cost efficiency provided that the threat of re-regulation is credible (Forsyth, 2004) and provided that an arbitration mechanism is in place to settle disputes between airports and airlines. It should be noted that the positive impacts of light-handed regulation on efficiency may cease to exist if the regulatory mechanism consists only of monitoring without the credible threat of re-regulation as has occurred in Australia.

It is desirable that regulatory institutions are independent and are controlled by the parliament. Such institutions are not susceptible to regulatory capture and provide long term commitment for immobile and specialized investment which has a positive impact on cost and allocative efficiency. Moreover, an independent regulator would encourage an airport not to set charges above the optimal level and would also encourage the regulated airport to minimize costs, which has a positive impact on cost efficiency.

2.3. Airport Efficiency Estimation

In analysing the performance of airports, it is useful to distinguish between productivity and efficiency. Productivity can be defined as the ratio of an aggregate measure of outputs to an aggregate measure of inputs. An airport which is technically efficient need not exhibit the maximum possible productivity. In order to achieve this, the technically efficient airport may have to move to another point on the production frontier which is the point of optimal scale. As a result, a technically efficient airport may be able to enhance its productivity by exploiting scale economies. Another source of productivity change over time is technical change. Consequently, improvement in productivity can be attributed to efficiency improvements, exploitation of scale economies and technical change (Coelli et al., 2005, pp. 2-6).

In analysing the efficiency of airports, it is worthwhile differentiating between technical, cost and allocative efficiency. An airport is technically efficient if it is able to produce the maximum output given its set of inputs or if it is able to produce a given level of output utilizing the minimum set of inputs while still remaining within the feasible production set. An airport is cost efficient if it produces a particular output at minimum cost given the input prices it faces. Input oriented allocative efficiency is the airport's ability to select the correct mix of input quantities such that the input price ratios equal the ratios of the corresponding marginal products. Output oriented allocative efficiency is the airport's ability to select the combination of output quantities such that the ratio of output prices equals the ratio of marginal costs (Coelli et al., 2003, pp. 11-12). At airports with spare capacity, Ramsey pricing can maximize output oriented allocative efficiency while at airports with excess demand, uniform peak pricing with slot constraints maximizes output oriented allocative efficiency.

It is also useful to analyse the scale efficiency of airports. An airport which exhibits technical and allocative efficiency may not be operating at the optimal scale. Suppose that an airport is using a variable returns-to-scale technology, it may be too small operating with increasing returns-to-scale meaning that a doubling of the inputs more than doubles the output in which case it is optimal for the airport to increase its capacity. On the other hand, the airport may be too large operating with decreasing returns-to-scale meaning that a doubling of the inputs less than doubles the outputs in which case it is optimal for the airport to scale down its operations. In both of these cases, it is optimal for the airport to utilize the same input mix but change the size of its operations. On the other hand, an airport which exhibits technical and allocative efficiency and operates with constant returns-to-scale globally can be automatically deemed scale efficient (Coelli et al., 2005, pp. 58-61). Airports could be natural monopolies due to the existence of sub-additive cost functions, which means that the total cost of production of a certain level of output by a single airport will be lower than the sum of total costs of production of a fraction of the output by multiple airports. Lechmann and Niemeier (2013) review studies analysing airport returns-to-scale and reach the conclusion that while returns-to-scale may be limited, economies of scope exist and play an important role in the measurement of airport efficiency.

In this section, we discuss the methodologies that are used to measure airport productivity and efficiency. We first discuss TFP, followed by the two frontier approaches namely SFA based on regression and DEA based on mathematical programs.

2.3.1. Total Factor Productivity

TFP is the ratio of aggregate output produced relative to aggregate input used when a firm makes use of multiple inputs and outputs. TFP change can be defined as the comparison of outputs produced in two periods with the maximum level of outputs utilizing given inputs operating under the reference technology. TFP is an aggregate productivity measure which can be estimated in several ways including parametric approaches, assuming production functions and non-parametric index number approaches. In making index number based TFP computations, it is assumed that a firm exhibits technical and allocative efficiency. In order to make comparisons between many firms, index numbers are derived such that they are transitive (Coelli et al., 2005, pp. 61-123).

In this section, we discuss the index number approach proposed by O'Donnell (2012b) and its application to the airport sector (See and Li, 2015). This is called the Hicks-Moorsteen TFP index which is a multiplicative index formulated as the ratio of Malmquist output and input quantity indices. The advantage of this index is that it requires only information on quantity, does not require any assumptions to be made with respect to a firm's returns-to-scale and behaviour and does not assume a specific production function. Another advantage of this index number approach is that the derived measure of TFP can be disaggregated into multiple components such as technical change and measures of efficiency change including technical efficiency, scale efficiency, mix efficiency and residual scale efficiency. See and Li (2015) apply the input oriented, Hicks-Moorsteen index number TFP formulation of O'Donnell (2012b) to measure the productivity of 22 UK airports over a nine year timeframe. The inputs include the number of employees, capital stock and cost of other inputs. The outputs include both aeronautical and non-aeronautical revenues. All monetary measures are deflated by appropriate price deflators.

2.3.2. Stochastic Frontier Analysis

Estimation of the production function of a given output and the efficiency with which each firm operates is of interest to study and improve performance at the firm and aggregate levels, in addition to the implementation of economic regulation. A popular framework for carrying out such estimation is the SFA model, in which the output is composed of three terms. The first term estimates the underlying production function, which expresses the relationship between the inputs and the outputs. The second term is a random effect term, asymmetrically distributed, which reflects the efficiency of the individual firm. The third term is a random error component, typically assumed to be symmetrically distributed, which accounts for the combined effects of various types of errors such as the inadvertent omission of relevant variables from the production function, errors of measurement in inputs and approximation errors.

Aigner et al. (1977) and Meeusen and van den Broeck (1977) introduced the concept of a stochastic frontier, aimed at incorporating producer-specific random shocks into the analysis. In SFA, the output is modelled such that the stochastic production frontier consists of two parts; a deterministic production function common to all producers and a producer-specific part which captures the effect of random shocks experienced by the producer. We subsequently obtain the production frontier and the technical efficiency with the assumption that technical efficiency takes a value below one and that the random effect term has a value greater than or equal to zero. The random effect term and the random error component are independent and identically distributed across the firms and the noise component is assumed to be symmetrically distributed and independent of the random effect term. Consequently, the error term is asymmetric, since the random effect term is greater than or equal to zero. Another standard assumption is that the random effect term and the random error component are independent of the inputs. Parametric forms are assumed for the random effect term and the random error component. Distributions commonly used for the random effect term include the half-normal, truncated normal, exponential and gamma. Usually it is assumed that the random error component has a normal distribution.

Early papers on the SFA model assumed that the production function is a log-linear Cobb-Douglas (1928) function. More recent papers often assume that the production function follows the translog function. Of all the flexible forms, the translog functional form is the most frequently used because it provides a second order approximation to any structure and allows a large variety of substitution patterns. Regularity conditions are imposed by linear restrictions to the parameters. Assaf and Gillen (2012) estimate a semi-parametric Bayesian stochastic translog distance function in order to measure the impact of governance form and economic regulation on the technical efficiency of airports from Europe, North America and Australia. The stochastic directional distance function permits an analysis of multiple inputs and multiple outputs simultaneously (Coelli and Perelman, 2000).

An alternative model estimates a stochastic cost frontier which requires a vector of input prices. Assaf (2010) makes a Bayesian random effects stochastic cost frontier estimation in order to analyse the cost efficiency of Australian airports post privatization. Assaf et al. (2012) estimate a Bayesian dynamic stochastic cost frontier in order to analyse the performance of airports in the UK. Assaf et al. (2014) estimate a random effects Bayesian dynamic inefficiency stochastic frontier in order to analyse the technical, cost and allocative efficiency of airports from Europe, North America and Australia.

For those interested in greater depth, we refer you to the book of Kumbhakar and Lovell (2003) and for panel data applications, the surveys of Cornwell and Schmidt (2008) and Kumbhakar et al. (2020).

2.3.3. Data Envelopment Analysis

DEA is a non-parametric method of frontier estimation that measures the relative efficiency of firms, often denoted as decision-making units, utilizing multiple inputs and outputs. DEA accounts for multiple objectives simultaneously without attaching ex-ante weights to each indicator and compares each decision-making unit (DMU) to the efficient set of observations, with similar input and output ratios, assuming neither a specific functional form for the production function nor the inefficiency distribution. DEA was first published in Charnes et al. (1978) under the assumption of constant returns-to-scale[2] and was extended by Banker et al. (1984) to include variable returns-to-scale. This non-parametric approach solves a linear program per DMU and the weights assigned to each linear aggregation are the decision variables of the mathematical program. The weights are chosen optimally in order to show the specific DMU in as positive a light as possible, under the restriction that no other DMU is more than 100% efficient with the same set of weights. This approach allows each firm to set its own priorities, whether input minimizing given the outputs to be served or output maximizing given

[2] Constant returns-to-scale means that the producers are able to linearly scale the inputs and outputs without increasing or decreasing efficiency.

a set of inputs available. Consequently, a Pareto frontier is estimated, marked by specific DMUs on the boundary envelope of input-output variable space. With DEA, we obtain a relative efficiency score, where a value of one indicates efficiency and a value smaller than one in an input oriented DEA model indicates the level by which the relevant inputs ought to be decreased in order for a DMU to be deemed relatively efficient. Either the input or the output orientation may be considered reasonable when benchmarking airports depending on the long run or short run nature of the analysis (Adler and Liebert, 2014; Curi et al., 2011; Karanki and Lim, 2020). In addition, Adler et al. (2015) apply a non-oriented variable returns-to-scale bound adjusted DEA in order to analyse the impact of regulation on the technical efficiency of airports from Europe and Australia.

For those interested in reading in greater depth, we refer you to Cooper et al. (2000) and Zhu and Cook (2007), the review papers of Liu et al. (2016) and Emrouznejad and Yang (2018) and the discussion of how to apply the modelling approach in Cook et al. (2014).

2.4. Impact of Regulation on Airport Performance

In this section we review the papers that have measured the impact of regulation on airport performance. We first describe the inputs and outputs that have been used in the studies. Here we also analyse whether the studies have explicitly measured the impact of regulation on efficiency. Next we review the studies that have analysed the impact of regulation on airport performance and charges.

2.4.1. Inputs, Outputs and Measuring the Impact of Regulation (Data Issues and Implications for Robustness of Results)

Multiple papers have been published applying the benchmarking methodologies described in Section 2.3 to the airport industry in an attempt to answer the open questions defined in Section 2.2. The papers published on the topic are summarised in Table 2.2. The research jointly analyses airports around the globe and the variables most frequently collected for this purpose draw from the KLEMS model (O'Mahony and Timmer, 2009). Capital (K) has been accounted for by measuring the capital stock (Bottasso and Conti, 2012; See and Li, 2015). Other studies use proxies for capital such as declared runway capacity, airport area, number of runways, apron area and total size of the passenger terminal (Adler and Liebert, 2014; Adler et al., 2015; Assaf and Gillen, 2012; Assaf et al., 2014; Curi et al., 2011). All cost efficiency studies use the price of capital as a factor input (Assaf, 2010; Assaf et al., 2012; Cambini and Congiu, 2022). Labour (L) is generally measured by full-time equivalent employees (Assaf and Gillen, 2012; Adler et al., 2015; Randrianarisoa et al., 2015; See and Li, 2015) or staff costs (Adler and Liebert, 2014). All cost efficiency studies include the price of labour as a factor price input (Assaf, 2010; Assaf et al., 2012; Cambini and Congiu, 2022). Variable costs generally include energy (E), materials (M) and supplies (S) in an aggregated form (Curi et al., 2011; Assaf and Gillen, 2012; Adler and Liebert, 2014; Adler et al., 2015; Randrianarisoa et al., 2015; See and Li, 2015). In the cost efficiency models, the price of services and materials, the materials and contracted services index and the purchasing power parity index are applied (Assaf et al., 2012; Assaf et al., 2014; Cambini and Congiu, 2022). The airport production process is characterized by the presence of multiple outputs, including passengers, aircraft movements, cargo, aeronautical revenues and commercial revenues. Sometimes work load units, a function of passengers and cargo, are utilized in order to address issues of excess variables.

It should be noted that some papers have not included all the necessary inputs and outputs in measuring technical, cost and allocative efficiency and this can impact the results obtained. This may be because the necessary data are not available. In some other cases, the studies include proxies for some inputs and outputs, which may not be a good measure for modelling the production process of airports. In measuring the cost efficiency of Australian airports, Assaf (2010) does not include the price of materials on the input side and he also does not include non-aeronautical revenues on the output side. In measuring the cost efficiency of airports in the UK, Assaf et al. (2012) include total revenues as a single output without differentiating this into aeronautical and non-aeronautical revenues. As a result, their study cannot analyse the relevance of one output in comparison to the other. Karanki and Lim (2020) use work load units as an output which may not be a good indicator of the passengers and cargo handled at the airports. This is because both passengers and cargo are different in their charging, use of resources and yield in revenues (Liebert and Niemeier, 2013). Randrianarisoa et al. (2015) do not include a measure of capital on the input side and they also do not include cargo handled on the output side. Assaf and Gillen (2012), Assaf et al. (2014) and Cambini and Congiu (2022) do not include cargo handled on the output side. Moreover, Cambini and Congiu (2022) do not include the passenger numbers on the output side. With respect to capital, only Bottasso and Conti (2012) and See and Li (2015) include capital stock on the input side as measured using the perpetual inventory method, which is the best measure of capital. The rest of the studies use proxies for capital because the data on capital stock may not be readily available or because of the problem of constructing a standardized measure of capital in cross-country comparisons. It should be noted that capital stock can be used to measure whether regulation leads to the Averch and Johnson (1962) effect, gold plating and cost padding while proxies for capital may not be suitable to measure such effects of regulation on airport efficiency.

With respect to regulation, some studies explicitly analyse the impact of regulation on efficiency while the others draw conclusions without a separate analysis of the impact of regulation on efficiency. Table 2.2 shows that studies such as Assaf et al. (2012), Adler et al. (2015), Adler and Liebert (2014), Karanki and Lim (2020), Randrianarisoa et al. (2015), Assaf and Gillen (2012), Assaf et al. (2014), See and Li (2015) and Cambini and Congiu (2022) have explicitly analysed the impact of regulation on efficiency. The remaining studies base their conclusions depending upon the views of the researchers, in which case the explanatory power of the results pertaining to regulation is limited.

Assaf et al. (2012) include a dummy variable that takes into account whether the UK airport is regulated or not. They also include a second variable that reflects the value of the price-cap of the regulated airport. Adler et al. (2015) include dummy variables for whether an airport has cost-based, revenue-cap, pure price-cap, hybrid price-cap or light-handed regulation. They also include a dummy variable that reflects whether an airport has a dependent or an independent regulator. Adler and Liebert (2014) test individual and combined effects of contextual variables on airport cost efficiency and aeronautical revenues. For the individual effects model, regulation has been categorized into no ex-ante, single-till cost-plus, dual-till cost-plus, single-till price-cap and dual-till price-cap regulation. They also include a dummy to represent the combinations of single or dual-till price-cap regulation at congested and uncongested airports respectively, which is used to explain aeronautical revenues. For the combined effects model, regulation has been classified as ex-ante unregulated and ex-ante regulated airports. Karanki and Lim (2020) introduce one binary variable for compensatory use agreements and another for hybrid use agreements with the control group being airports which have residual use agreements in order to study the impact of regulation on the efficiency of airports in the US. They use bootstrapped bias corrected efficiency scores as the dependent variable in the second stage truncated regression model. Randrianarisoa et al. (2015) classify the forms of airport economic regulation according to no ex-ante regulation, single-till cost-plus regulation, dual-till cost-plus regulation, single-till price-cap regulation, dual-till price-cap regulation and charges set by airports (single and dual-till). Assaf and Gillen (2012) classify regulation as rate-of-return, single-till, dual-till, price monitoring and no regulation. In their analysis, they combine regulation and ownership to get seven levels of combinations of ownership and regulation. Assaf et al. (2014) use the same regulation and ownership combinations as in Assaf and Gillen (2012). See and Li (2015) use a dummy variable that categorizes the UK airports as either regulated or unregulated. Cambini and Congiu (2022) introduce a binary variable that identifies the treated (regulated) airports in the years of the treatment. Moreover, as the impact of regulation may take some years to manifest, Cambini and Congiu (2022) include an additional variable that takes the value of one in the year of adoption of regulation by the airport, the value of two one year after the adoption of regulation by the airport and so on. This variable takes the value of zero in all other cases. The authors also perform robustness checks by introducing a variable that takes the value of one only in the relevant year pertaining to regulation.

It is useful to analyse whether the impact of regulation on efficiency has been separated from other factors such as ownership and competition. Assaf et al. (2012) separate the effects of regulation from the effects of competition. Adler et al. (2015) do not include variables that account for competition and ownership. Adler and Liebert (2014) and Randrianarisoa et al. (2015) separate the impacts of ownership and competition from regulation. Karanki and Lim (2020) separate the impact of regulation from the impact of governance. Assaf and Gillen (2012) and Assaf et al. (2014) measure the combined impact of ownership and regulation on efficiency but they do not measure the impact of competition on efficiency. See and Li (2015) separate the impact of ownership from the impact of regulation. Cambini and Congiu (2022) do not separate the impact of regulation from the impacts of ownership and competition. As a result, Adler and Liebert (2014) and Randrianarisoa et al. (2015) have the most detailed second stage analysis.

2.4.2. The Impact of Regulation on Airport Performance and Charges

With regards to cost-plus regulation, Randrianarisoa et al. (2015) argue that regulation has little to no noticeable impact on efficiency levels. They evaluate the impact of corruption on the technical efficiency of 47 airports from 27 European countries from 2003 to 2009. Wren-Lewis (2013) argues that an independent regulator may reduce the effect of corruption on efficiency, hence Randrianarisoa et al. (2015) include a regulation variable as a control. The results with respect to regulation are statistically insignificant in a random effects model but are significant in a pooled OLS model, which suggests that cost-plus, single-till regulated airports are more efficient than unregulated airports which in turn are more efficient than incentive, dual-till regulated airports. Nevertheless, as they use the random effects model for inference, they conclude that regulation has no significant impact on the performance of the analysed airports. With regards to their pooled OLS model, the results that they obtain are rather strange as incentive regulation is superior to cost-plus regulation in terms of the impact that it has on airport efficiency.

Adler et al. (2015) analyse the impact of cost-based and incentive regulation on the short-term technical efficiency of 58 European and Australian airports from 1990 to 2010 using a two stage benchmarking and regression methodology. For the second stage fixed effects and truncated regressions, they categorize incentive regulation as high powered pure price-caps, medium powered hybrid price-caps and light-handed monitoring, and low powered revenue-caps. After controlling for the share of revenues from non-aeronautical activities and capacity utilization, they find that incentive regulation leads to higher productive efficiency in comparison to cost-plus regulation. Their categorization of whether the regulator is dependent or independent was not proven to significantly impact productive efficiency. Adler and Liebert (2014) analyse the combined impact of competition, ownership form and regulation on the cost efficiency and prices of an unbalanced panel dataset of 48 European and Australian airports from 1998 to 2007. Their results suggest that cost-plus regulation creates disincentives for efficiency whereas dual-till incentive regulated airports are more cost efficient than their single-till incentive regulated counterparts. In weakly competitive markets, majority privately owned and regulated airports are more efficient than their unregulated counterparts whereas publicly owned and regulated airports perform worse than those that are unregulated. In a potentially competitive environment, the results suggest that both purely public and purely private airports operate in an equally cost efficient manner. Furthermore, the private and unregulated airports perform better than their regulated counterparts, suggesting that regulation creates costs to both the regulators and the regulated firms. However, it is also noted that the aeronautical prices of unregulated private airports tend to be higher than their unregulated public counterparts. Consequently, Adler and Liebert conclude that fully private, dual-till, price-cap regulated airports are the most cost efficient under weak competition. Under potential competition, both ownership forms are equally cost efficient, but unregulated private airports charge a higher price than their unregulated public counterparts. Karanki and Lim (2020) analyse 59 of the large and medium sized US airports from 2009 to 2016. Their results suggest that state government owned airports are less efficient than their counterparts operated by a port or airport authority. With respect to regulation, their results suggest that airports operating under compensatory or hybrid methods are more efficient than those with residual agreements signed with a signatory airline. Whilst the signatory airlines may enjoy lower charges, the airport is less incentivised to achieve operational efficiency goals.

With regards to price-cap regulation, Assaf et al. (2012) estimate the impact of price-cap regulation and the level of the price-cap on the cost efficiency of 27 large UK airports from 1998 to 2008. The results suggest that average cost efficiency was relatively high and improved over time. Factors found to be important determinants of efficiency include airport size, level of competition, the existence of single-till price-cap regulation and the price-cap value. The authors note that the lower efficiency found at airports with a higher price-cap does not necessarily imply cost inefficiency rather this may reflect the need for an investment program. Bottasso and Conti (2012) estimate short and long run translog variable cost functions for 25 airports located in the UK covering the years 1994 to 2005. The results suggest a positive technical change of around 2% annually but equally over-capitalization among the larger airports. The long run average cost functions suggest that airports with under five million passengers enjoy increasing economies of scale and those with over 15 million passengers suffer from diseconomies of scale. The authors argue that the UK Civil Aviation Authority sets prices which match average costs and that these suboptimal prices lead to allocative inefficiencies. See and Li (2015) estimate the impact of size, regulation and ownership form on the total factor productivity of 22 UK airports from 2001 to 2009. The results indicate that the majority of the sample experience TFP growth but technical regress explains a reduction in TFP for the minority. The results also show lower TFP growth rates for regulated airports as compared to those that are unregulated.

Curi et al. (2011) analyse the operational and financial efficiency of 18 Italian airports from 2000 to 2004. Their measure of financial performance is technical efficiency with financial inputs and outputs such as labour costs and other costs for inputs and aeronautical and non-aeronautical revenues for outputs. The results of the financial analysis suggest a net increase in efficiency over the time duration considered after dual-till price-caps were introduced in 2001. However, operational efficiency declined, likely due to the large decrease in traffic as a result of the terrorist attacks in the United States on September 11th, 2001. Cambini and Congiu (2022) use a difference-in-differences framework to analyse whether dual-till price-cap regulation with a negotiation procedure introduced after the setting up of the independent Italian transport regulation authority in 2013 has significantly reduced the average costs of the regulated airports. They use an 11 year balanced panel dataset of 22 Italian airports observed from 2008 to 2018 for their analysis with the regulated airports being the treatment group and the unregulated airports being the control group. They find that the newly introduced regulatory mechanism has a significant effect in reducing average costs of the regulated airports. Their results show that the dual-till price-cap regulated airports have an initial increase in average costs followed by a decrease in average costs over the years. The authors argue that the initial increase in average costs occurs because the airports have to adapt to the new regulation. The subsequent significant decline in average costs leads the authors to infer that dual-till price-cap regulation with a negotiation procedure increases the efficiency of the regulated airports due to the effect of the incentive mechanism. The authors conclude that the change in regulation has a positive effect on the overall efficiency of the Italian airport system.

Reference	Region	Timeframe	Method	Performance Measure	Inputs	Outputs	Impact of Regulation Explicitly Analysed	Results
Regulation impacts positively on estimated levels of efficiency								
Assaf (2010)	Australia	2002 – 2007	Bayesian random effects stochastic frontier analysis	Cost efficiency	Price of labour, price of capital	Passengers, cargo, aircraft movements	No	Light handed regulation leads to cost efficiency
Assaf et al. (2012)	UK	1998 – 2008	Bayesian dynamic stochastic frontier analysis	Cost efficiency	Price of labour, price of capital, price of materials	Total revenues	Yes	Price-cap regulated airports more cost efficient but level of price-cap important
Bottasso and Conti (2012)	UK	1994 – 2005	SURE and 3SLS	Variable cost function	Capital stock, price of labour, price of variable inputs	Work load units, aircraft movements, non-aeronautical revenues	No	Technical efficiency increased over time but regulation causes over-capitalization at larger airports suffering diseconomies of scale
Curi et al. (2011)	Italy	2000 – 2004	Output oriented constant returns-to-scale bootstrapped DEA	Operational efficiency and financial efficiency	Operational efficiency – Labour, number of runways, apron size Financial efficiency – Labour costs, other costs, airport area	Operational efficiency – Passengers, cargo, aircraft movements Financial efficiency – Aeronautical & non-aeronautical revenues	No	Dual-till price cap regulation improved financial efficiency but was introduced in 2001, alongside terrorist attacks which reduced demand globally, hence operational efficiency dropped
Adler et al. (2015)	Europe and Australia	1990 – 2010	Non-oriented variable returns-to-scale bound adjusted DEA	Technical efficiency	Labour, other operating costs, runway capacity	Non-aeronautical revenues, passengers, aircraft movements, cargo	Yes	Incentive regulation leads to higher productive efficiency in comparison to cost plus regulation
Adler and Liebert (2014)	Europe and Australia	1998 - 2007	Input oriented variable returns-to-scale weighted additive DEA	Cost efficiency	Staff costs, other operating costs, declared runway capacity	Passengers, cargo, aircraft movements, non-aeronautical revenues	Yes	Under weak competition, private owned, dual-till price-cap regulated airports

Reference	Region	Timeframe	Method	Performance Measure	Inputs	Outputs	Impact of Regulation Explicitly Analysed	Results
								more efficient than unregulated counterparts In competitive environment, purely public and purely private unregulated airports operate equally cost efficiently but private airports set higher aeronautical charges
Karanki and Lim (2020)	United States	2009 - 2016	Bootstrapped output oriented DEA	Technical efficiency	Labour, effective number of runways, airport land area, gates, variable costs	Work load units, non-aeronautical revenues	Yes	Compensatory and hybrid agreements positively and significantly impact efficiency
Cambini and Congiu (2022)	Italy	2008 - 2018	Difference-in-differences	Average cost function	Price of capital, price of labour, price of services and materials	Aircraft movements, commercial revenues	Yes	Introduction of dual-till price-cap regulation with a negotiation procedure initially increases the average costs of the regulated airports but subsequently significantly reduces the average costs of the regulated airports
Regulation does not impact efficiency estimates								
Randrianarisoa et al. (2015)	Europe	2003 – 2009	Residual variable factor productivity	Variable factor productivity	Labour, soft-costs	Passengers, aircraft movements, non-aeronautical revenues	Yes	No significant difference in operating efficiency of airports whether regulated or not
Regulation impacts efficiency estimates negatively								

Reference	Region	Timeframe	Method	Performance Measure	Inputs	Outputs	Impact of Regulation Explicitly Analysed	Results
Assaf and Gillen (2012)	Europe, North America and Australia	2003 – 2008	Semiparametric Bayesian stochastic distance function	Technical efficiency	Labour, soft costs, number of runways and total size of passenger terminal	Passengers, aircraft movements, non-aeronautical revenues	Yes	Private airport subject to minimal economic regulation most efficient Government owned, single-till, cost based regulation least efficient
Assaf et al. (2014)	Europe, North America and Australia	2003 – 2008	Random effects Bayesian dynamic inefficiency stochastic frontier analysis	Technical, cost and allocative efficiency	Employees, materials & contracted services, runways, passenger terminal area, price of labour, purchasing power parity index	International passengers, other passengers, aircraft movements, non-aeronautical revenues	Yes	Economic regulation leads to reduced short-run technical efficiency
See and Li (2015)	UK	2001 - 2009	Input oriented Hicks-Moorsteen index number approach	Total factor productivity	Labour, capital stock, other operating expenses	Aeronautical & non-aeronautical revenue	Yes	Regulated airports attain lower productivity growth rates than unregulated airports
Impact of regulation on charges								
Bel and Fageda (2010)	Europe	2007	IV-2SLS	Pricing equation	Independent variables - Total traffic, % domestic traffic, nearby airports, HHI, % airline alliance traffic, private non-regulated dummy, island dummy, price-fixing system dummy, price-cap dummy, dual-till dummy	Dependent variable - Price	Yes	The type of regulation whether rate-of-return or price-cap has no significant effect on charges Private airports which are not regulated impose higher aeronautical charges than their public counterparts

Reference	Region	Timeframe	Method	Performance Measure	Inputs	Outputs	Impact of Regulation Explicitly Analysed	Results
Bilotkach et al. (2012)	Europe	1990 - 2007	System GMM dynamic panel data model	Pricing equation	Independent variables - Price-cap dummy, single-till regulation dummy, ex post regulation dummy, private ownership share, hub airport dummy, number of nearby airports, non-aeronautical revenue per pax, real GDP per capita, population, passengers per aircraft movements, cargo volume	Dependent variable - Aeronautical revenue per aircraft movement	Yes	Single-till regulated airports impose lower charges than dual-till regulated airports The type of regulation whether rate-of-return or price-cap has no significant effect on charges Privatized regulated airports impose lower aeronautical charges

Table 2.2: Overview of research on airport performance and charge estimation

With regards to light-handed regulation, Assaf (2010) analyses the cost efficiency of 13 major Australian airports from 2002 to 2007, approximately five years after the privatization of these airports. The results suggest that cost efficiency increased over time, which he hypothesizes is due to the privatization process and light-handed monitoring regulatory effects. Assaf and Gillen (2012) estimate the combined impact of governance form and regulation on the productive efficiency of 73 international airports from Europe, North America and Australia between 2003 and 2008. Their results suggest that fully private airports with light-handed regulation and government owned airports without regulation are the most technically efficient. The least efficient are those airports which are government owned and subject to cost-based, single-till regulation. Assaf and Gillen argue that the more restrictive the form of regulation, the lower the productive efficiency, regardless of the ownership form. Assaf et al. (2014) analyse the joint impact of ownership and regulation on the short and long run technical and allocative efficiency of airports for the same dataset. They conclude that economic regulation leads to reduced short-run technical efficiency except in the case of light-hand regulated, privately owned airports found in Australia and New Zealand. Regardless of governance type, they argue that removing single-till price-cap regulation will always improve economic efficiency and the expected gains are highest for fully or partially publicly owned airports.

With regards to charges, single-till regulated airports impose lower charges than dual-till regulated airports (Bilotkach et al., 2012) and the type of regulation whether rate-of-return or price-cap seems to have no significant effect on charges (Bel and Fageda, 2010; Bilotkach et al., 2012). This implies that those airports which have increased their efficiency have kept the gains realized from improved efficiency. While higher airport and intermodal competition lowers airport charges (Bel and Fageda, 2010), privatized airports which are regulated also impose lower charges (Bilotkach et al., 2012) and private airports which are not regulated impose higher charges than their public counterparts (Bel and Fageda, 2010; Adler and Liebert, 2014).

2.5. Conclusions and Future Directions

In summary, the applied literature has quite substantially analysed the impact of regulation on airport performance and charges. One explanation for the differing results is an argument over whether the US airports are regulated or not. Whilst Assaf and Gillen (2012) and Assaf et al. (2014) classify US airports as unregulated public airports, Graham (2004) describes residual, compensatory and hybrid regulatory approaches which are assessed in Karanki and Lim (2020). The latter estimate that compensatory (dual-till) US airports are more technically efficient than those with residual (single-till) use agreements. Moreover, the Federal Aviation Administration and US Department of Transport pose a credible threat of regulation and airports have been taken to court due to airline complaints. However, as airports in the US are regulated in a very different manner, their efficiency may have to be assessed separately as has been done in Karanki and Lim (2020). Consequently, we hypothesise that light-handed and incentive based regulation are the most conducive to improving performance in comparison to rate-of-return regulation based on the majority of the applied literature. Moreover, dual-till price-cap regulation is preferred over single-till regulation.

Table 2.3 reproduces Table 2.1 and shows whether the expected effects of regulation on efficiency have been analysed in the literature. The table shows that there is scope for further research. Adler and Liebert (2014) find that in markets with no competition, dual-till incentive regulation improves the efficiency of airports and in markets with potential competition, no regulation is needed as it may distort efficiency. Assaf and Gillen (2012) find that an unregulated government owned airport is more efficient than a government owned airport which is regulated with rate-of-return regulation. This gives some evidence that rate-of-return regulation does not necessarily lower charges and increase output in comparison to a monopolist. Further research is needed to test whether rate-of-return regulation provides no incentives to congested airports to pursue peak pricing and whether it leads to the Averch-Johnson effect, gold plating and cost padding.

Single-till rate-of-return regulation is argued to restrict potentially competitive commercial activities and this needs to be further researched. With respect to charges, Bilotkach et al. (2012) find that single-till regulation leads to lower aeronautical charges in comparison to dual-till regulation. With respect to price-cap regulation, while Assaf et al. (2012), Adler and Liebert (2014) and Cambini and Congiu (2022) find that this form of regulation leads to cost efficiency, further research is needed to test whether it provides airports with incentives to pursue peak pricing and whether it also provides airports with incentives to under-invest, which leads to a deterioration in service quality. Further research is also needed to test whether single-till price-caps provide weak incentives to earn commercial revenues. With respect to dual-till price-caps, Adler and Liebert (2014) find that cost efficiency is enhanced when dual-till price-caps are imposed on airports facing weak competition. This gives some evidence that dual-till price-caps encourage airports to lower aeronautical charges and increase passenger throughput. This also give some evidence that dual-till price-caps incentivize airports to earn more commercial revenues.

While Adler et al. (2015) do not find significant efficiency effects of having an independent regulator, Cambini and Congiu (2022) find that regulation by the independent Italian transport regulation authority significantly reduces average costs. This gives evidence that an independent regulator encourages airports not to increase costs above the optimal level. These are significant findings because many more countries now have independent airport regulators and there is renewed interest in the European Union to have independent airport regulators.

Market Structure/ Regulatory Environment	**Description**	**Research Analysing the Effect**
Monopoly	Restriction of output and unexploited economies of scale	Adler and Liebert (2014)
	Leads to *X*-inefficiency	Adler and Liebert (2014)
Competitive Market	Regulated airports may distort efficiency	Adler and Liebert (2014)
Rate-of-Return Regulation	Lower charges increase output in comparison to monopolist	Assaf and Gillen (2012)
	Congested airports have no incentive to set peak prices	Further research needed
	Averch-Johnson effect, gold plating and cost padding	Further research needed
Single-Till Rate-of-Return Regulation	Restricts potentially competitive commercial activities	Further research needed

Market Structure/ Regulatory Environment	Description	Research Analysing the Effect
Dual Till Rate-of-Return Regulation	Higher charges decrease output in comparison to single-till rate-of-return regulation	Bilotkach et al. (2012)
Price-Cap Regulation	Peak pricing promotes allocative efficiency	Further research needed
	Encourages cost efficiency	Assaf et al. (2012), Adler and Liebert (2014), Cambini and Congiu (2022)
	Under-investment leads to deterioration in quality of service	Further research needed
Single-Till Price-Cap Regulation	Leads ceteris paribus to lower caps compared to dual till	Bilotkach et al. (2012)
	Creates weak incentives to earn commercial revenues	Further research needed
Dual Till Price-Cap Regulation	Encourages airports to lower aeronautical charges thus increase passenger throughput, but ceteris paribus less than single till	Adler and Liebert (2014)
	Commercial revenues are unrestricted	Adler and Liebert (2014)
Light Handed Regulation	With credible threat and an arbitration mechanism, encourages cost efficiency and output oriented allocative efficiency	Assaf (2010)
	Flexible with a low amount of regulatory burden	Further research needed
	A congested airport has the incentive to practice peak pricing and an airport with excess capacity has the incentive to pursue Ramsey pricing	Further research needed
Independent regulator	Provides long term commitment for immobile and specialized investment	Adler et al. (2015)
	Prevents charges from increasing above the optimal level and also encourages airports not to increase costs above the optimal level	Adler et al. (2015), Cambini and Congiu (2022)

Table 2.3: Analysis in the literature of the effects of regulation on airport efficiency

While Adler and Liebert (2014) and Adler et al. (2015) find that rate-of-return regulation leads to cost and technical inefficiency, further research is needed to find the sources of inefficiency which have been analysed in Averch and Johnson (1962), Liston (1993) and Armstrong et al. (1994). Although price-cap regulation is found to be superior to rate-of-return regulation, further research is needed to find the sources of efficiency gains which have been analysed in Beesley and Littlechild (1989).

It is argued that price-cap regulation may lead to underinvestment and a lower service quality. For this to be analysed, service quality will have to be included as an output as has been done in Merkert and Assaf (2015). As Assaf et al. (2012) find that a higher price-cap leads to a lower cost efficiency of airports in the UK, this gives evidence that this form of regulation can lead to higher price-caps in the presence of informational asymmetries. However, further research is needed to test whether some airlines are not served due to the presence of a price-cap and whether the lack of rate hearings leads to lower airport efficiency.

Assaf (2010) finds that light-handed regulation leads to high cost efficiency of airports in Australia. This is because light-handed regulation is a flexible mechanism and the regulator posed a credible threat of re-regulation during the first period of light-handed regulation in Australia. Further research should focus on whether the negotiate/arbitrate model and efficiency oriented light-handed regulation are superior to the review/sanction approach and cost-based light-handed regulation respectively.

Another aspect of airport regulation that needs further research is slot allocation. Two important aspects are the slot capacity limit and the comparison of slot allocation to queuing. Pels et al. (2003) find that slot coordinated European airports are more technically efficient than those European airports which are not slot coordinated. This maybe because slot coordinated European airports achieve a higher capacity utilization. There is a trade-off between the slot capacity limit and the level of congestion. In fact, Adler and Liebert (2014) find that heavy delays have a negative impact on cost efficiency and a runway utilization of above 90% has a positive impact on cost efficiency. Moreover, Adler and Yazhemsky (2018) find that the benefits of adding a slot at peak-periods at congested European airports outweigh the congestion and delay costs of the additional slot. It is thus interesting to further analyse the right slot capacity limit and its implications for airport efficiency. With respect to the comparison of slot allocation and queuing, Jacquillat and Odoni (2018) find that slot allocation is superior to queuing in relation to capacity, delay and congestion management, although this depends on how optimally the slot constraint is set. Nevertheless, due to the trade-off between capacity utilization and delay and congestion management, it is interesting to compare slot allocation and queuing from a benchmarking perspective. A step further would be to analyse whether price-capped airports which are congested have an incentive to pursue peak pricing and the impact of such peak pricing on their efficiency.

In addition to the points identified above, further research should also focus on airports in developing regions of the world to test whether the results hold true also for airports in developing countries. Furthermore, investment regulation has not been studied in depth in the literature. Analysing the efficiency implications of the points identified in this section will give a better understanding of how regulation impacts airport performance and charges.

In conclusion, we argue that regulation most likely impacts airport efficiency and for the most part, appears to positively encourage technical and cost efficiency. Moreover, the question of the impact of regulation on efficiency should not be divorced from the impact of governance form and competition levels. In other words, airports located in regions with little to no competition from either alternative airports or transport modes, will require a form of regulation in order to ensure reasonable charge levels. In such cases, regulation should be subject to a cost benefit analysis. The general consensus appears to be dual-till incentive regulation with quality monitoring and cost pass-through using the RAB. As the literature shows that private regulated airports and public airports impose lower charges than private unregulated airports (Bel and Fageda, 2010; Bilotkach et al., 2012; Adler and Liebert, 2014), charges of airports with little competition and significant market power should be regulated in order to optimize overall social welfare. In markets with competition and in markets where airports have no significant market power, regulation is unnecessary and simply leads to additional costs. We also find that light-handed regulation leads to efficient airports. However, such airports are not necessarily the cheapest because this is a function of the competition that they face.

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Chapter 3

The impact of specialization, ownership, competition and regulation on efficiency: a case study of Indian seaports[3]

Abstract

We develop a two-stage formulation to estimate seaport performance and to understand the drivers of efficiency, which could potentially include specialization, ownership, competition and tariff regulation. The first-stage non-parametric, slacks-based measure estimates the technical efficiency of each port. For the second-stage analysis, we develop a set of contextual variables including an absolute measure of specialization and a berth-level measure of ownership structure. To measure competition, we develop spatial measures that quantify the level of competition as a function of distance. We subsequently apply this formulation to major Indian seaports, covering a period of 21 years, from 1995 to 2015. The first-stage results suggest that average seaport efficiency has increased gradually over time. The second-stage fixed effects regressions show that specialization and external stakeholder participation have significant positive impacts on seaport performance. Perhaps surprisingly, we find that, in a tiered governance framework, competition between major seaports and local seaports has a significant negative impact on performance, potentially due to excessive infrastructure. Finally, changes in the regulatory mechanism over time are shown to be efficiency improving.

***Keywords*:** Indian seaports, technical efficiency, specialization, ownership, competition, tariff regulation

3.1. Introduction

A five-fold increase in commodity exports from 1995 to 2011 (UNCTAD, 2013) and the emergence of global production processes have led to port reforms over the last two decades. Recurring themes include ownership restructuring, a reduction in the role of the public sector, and improvement in the quality of seaport performance. The devolution of the public sector from port operations has resulted in an increase in private sector participation and in independent regulatory institutions for seaports (Brooks et al., 2017). The most prevalent governance model arising from port reforms has been the landlord port model. According to the World Bank (2001), the landlord seaport model contracts out port operations to the private sector, and the terminal operator thereafter invests in the *superstructure*, i.e. cargo-handling technology. The terminal operator is in turn eligible to earn returns on the investments made for a predetermined concession period. Under the landlord model, common port infrastructure is either funded by the port authority, by the private sector, or through a public–private partnership agreement. This is in contrast to the public service seaport model which was common before the emergence of port reforms. In a public service seaport, the port authority is responsible for port planning, management and operations. Nautical-technical services (pilotage, towage, mooring and, maybe, dredging) may be provided by a sole private firm (competition *for* the market), by a number of them competitively (competition *in* the market),

[3] The research of this chapter is obtained in collaboration with Prof. Dr. Nicole Adler, Hebrew University of Jerusalem, Prof. Dr. Georg Hirte, TU Dresden and Prof. Dr. Hans-Martin Niemeier, Hochschule Bremen City University of Applied Sciences. This chapter has been published in Maritime Economics & Logistics, 2021. This chapter has been reproduced with permission from Springer Nature.

by the port authority, or by a public–private partnership agreement. We attempt to assess whether the port reforms and the landlord model have led to improved efficiency, including a better use of resources, increases in cargo throughput and changes in quality of service. To that effect, we create a performance framework which is then applied to the Indian seaport market and thereafter test the impact that governance related port reforms have had on the performance of said seaports.

Performance analyses have been proposed as a basis for incentive-oriented regulatory tools (Barros, 2003; Estache et al., 2004; Ferrari and Basta, 2010). Accordingly, we build measures for reform-related contextual factors such as specialization, ownership structure, competition levels and economic regulation, and test their impact on seaport performance. Mixed results have been obtained with regard to the impact of specialization or diversification strategies on seaports (Martinez-Budria et al., 1999; Inglada and Coto-Millan, 2010; Tovar and Wall, 2017; Hidalgo-Gallego et al., 2020). Mixed results have also been obtained with regard to the impact of private participation (Cullinane et al., 2005a; Cheon et al., 2010; Wang et al., 2013; Yuen et al., 2013; Wanke and Barros, 2015; Zheng and Yin, 2015) and seaport competition (Yuen et al., 2013; Oliviera and Cariou, 2015; Merkel, 2018). As a result, evidence from the existing literature has been inconclusive as to whether specialization, private sector participation and competition lead to an enhancement in seaport performance.

In this research, we apply a two-stage analysis to measure the impact of reform measures on performance, and we collected data on Indian seaports over the last two decades for this purpose. We estimate the relative performance of 11 port authorities in the first stage, which handled 56% of the cargo in 2015[4]. We collected data from the annual publications of the Indian Ports Association (1996–2016), wherein detailed profiles of all the major ports have been provided. Our unbalanced panel data set spans 21 years from 1995 to 2015. Our first-stage performance estimates present a relative technical efficiency measure, obtained using a slacks-based measure of technical efficiency (Tone, 2001). In the second stage, we apply fixed effects regression models to ascertain the impact of reform-related factors, including specialization, external stakeholder participation (Denktas-Sakar and Karatas-Setin, 2012), competition from local state-owned seaports, and economic regulation on the relative technical efficiency of the major seaports of India.

This research contributes to the extant literature in two directions. First, we develop a berth-level measure of ownership structure, a spatial measure of competition between ports and an absolute measure of specialization, namely the Keeble and Hauser (1971) Herfindahl–Hirschman Index (HHI) on seaport efficiency, which to the best of our knowledge have not been applied in the transport literature to date. Second, we measure the combined impact of ownership structure, competition and tariff regulation on seaport performance, which has not been studied before either. Moreover, previous research on Indian seaports has analysed the technical efficiency of (i) major Indian seaports (Kamble et al., 2010; Sekar and Deo, 2012; Sekar et al., 2014; Dasgupta and Sinha, 2016; Monteiro, 2018), (ii) minor Indian seaports (Sekar and Deo, 2016) and (iii) public and private Indian container terminals (Iyer and Nanyam, 2020). This paper adds to the existing literature by estimating the technical efficiency of the major Indian seaports over two decades and by analysing the combined impact of

[4] The figure represents the cargo handled in financial year 2015–2016, which runs from 1 April 2015 to 31 March 2016. This has been written as 2015 for the sake of convenience. The same format has been used for the rest of the paper.

relevant contextual factors on port technical efficiency. Our results may be useful for public policy decision-making with respect to Indian seaports and beyond.

The rest of the paper is organized as follows: a literature survey of the port production process and the impacts of contextual factors on seaport performance is discussed in Section 3.2, seaport governance and the reforms in India are detailed in Section 3.3, the research methodology, variables and data set included in this research are described in Section 3.4, the results are discussed in Section 3.5, and conclusions are drawn and recommendations for further research are provided in Section 3.6.

3.2. Literature Survey

Port performance is often measured by modelling the production process of seaports. Odeck and Bråthen (2012) categorize frontier methodologies, which have been used to measure seaport performance. They note that most studies use either data envelopment analysis (Charnes et al., 1978; Banker et al., 1984) or stochastic frontier analysis (Aigner et al., 1977) to measure technical efficiency of seaports. Data envelopment analysis (DEA), the method applied in this research, is a non-parametric, deterministic approach to measure performance which relies on linear programming to identify the efficiency frontier.

Our objective is to understand the port production process and the input and output factors we have to consider while conducting a seaport performance study. As we are focusing on technical efficiency, we divide the variables according to a broad classification of the production factors. Since we apply DEA in this research, we have reviewed published seaport DEA papers to categorize the most relevant variables. The reader is referred to Panayides et al. (2009) and Gonzales and Trujillo (2009) for literature surveys and to Odeck and Bråthen (2012) for a meta-analysis of DEA and stochastic frontier analysis studies on the technical efficiency of seaports. From the literature survey, we conclude that both inputs and outputs for seaports are broadly classified into three factors. On the input side, these represent capital, labour and short-term variable costs, and on the output side, these are cargo, monetary and service quality measures.

3.2.1. Inputs

Capital is an important input, but it is often also the most difficult to measure. The book value of assets (Roll and Hayuth, 1993; Barros, 2003; Barros and Athanassiou, 2004) is frequently used, although the perpetual inventory method (Goldsmith, 1951; application to transport see for example Waters and Tretheway, 1999) would be preferable if required information is available. When this information is not available, the most commonly used monetary proxy for capital is depreciation (Martinez-Budria et al., 1999). Capital has also been proxied by berth and yard side physical assets, including the number of berths (Tongzon, 2001; Itoh, 2002), total quay length (Estache et al., 2004; Cullinane et al., 2004, 2005a, b, 2006; Turner et al., 2004; Wang and Cullinane, 2006), berthing capacity (Park and De, 2004), terminal area (Tongzon, 2001; Itoh, 2002; Cullinane et al., 2004, 2005a, b, 2006; Turner et al., 2004; Wang and Cullinane, 2006) and cargo-handling capacity (Park and De, 2004). Moreover, cargo handling equipment, including the number of cranes (Tongzon, 2001; Itoh, 2002; Cullinane et al., 2004, 2005a, b, 2006; Turner et al., 2004), tug boats (Tongzon, 2001) and straddle carriers (Cullinane et al., 2004, 2006, 2005a, b) have also been used as proxies for capital.

Seaports are capital-intensive investments, and there is a trend among seaports to substitute away from labour towards more mechanized or automated technology. Labour is still an important factor that needs to be taken into consideration. This variable is not always easy to measure as port authority labour is often outsourced. When outsourced employee figures are available, care must also be taken to include the nature of employment, e.g. the proportion of full-time and part-time employees or employee-hours. Some proxies for labour include the number of port authority employees (Roll and Hayuth, 1993; Tongzon, 2001; Itoh, 2002; Barros, 2003; Estache et al., 2004; Barros and Athanassiou, 2004) or expenditure on salaries (Martinez-Budria et al., 1999) when precise information on outsourcing and the nature of employment of cargo-handling workers is not available. The third input includes the variable cost of port authority operations over and above its expenditure on salaries and depreciation (Martinez-Budria et al., 1999).

3.2.2. Outputs

The most important output measure is the amount of cargo handled at the seaports. While the mass of cargo handled (Roll and Hayuth, 1993; Martinez-Budria et al., 1999; Estache et al., 2004; Park and De, 2004; Barros and Athanassiou, 2004) has most commonly been included, in some cases container counts have also been assessed (Tongzon, 2001; Itoh, 2002; Barros, 2003; Barros and Athanassiou, 2004; Cullinane et al., 2004, 2005a, b; 2006; Turner et al., 2004; Wang and Cullinane, 2006). Some studies have divided the cargo handled into different categories to account for the multi-output nature of the port production process (Barros, 2003). Furthermore, the vessel calls (Roll and Hayuth, 1993; Tongzon, 2001; Barros, 2003; Barros and Athanassiou, 2004; Park and De, 2004) are included to consider operations at the level of the berth. As a result, cargo handled accounts for the operations in the terminal yard and vessels handled accounts for berth-side operations.

The operating income could be an alternative to cargo measures. Both total revenues and net income have been used as outputs (Martinez-Budria et al., 1999; Park and De, 2004). Care should be taken not to include cargo and monetary measures in the output side in order to avoid double counting outputs. The revenue that the port authority earns is a function of cargo and vessel handling, or revenue (fees) from concession contracts.

Quality of service could also be considered as an output in a seaport performance analysis. Subjective measures of the quality of service have been obtained through user satisfaction surveys (Roll and Hayuth, 1993; Park and De, 2004). Roll and Hayuth (1993) define an objective measure of the level of service, which is the ratio between the handling time and the total time a ship remains in port. Another objective measure is to count the container moves per working hour per ship for a container port or terminal (Tongzon, 2001). More recently, negative externalities have been accounted for by including port emissions as an undesirable output within the DEA methodology. For example, Chang (2013) includes CO_2 emissions as an undesirable output in the DEA model examining port efficiency.

3.2.3. Contextual Factors

From Kemeny and Storper (2012), a specialized seaport is one that mostly handles one type of cargo and a diversified seaport is one that handles many types of cargo, with no cargo type dominating the composition. Ducruet et al. (2010) argue that seaport diversification strategies are policy matters relevant to both local and national governments. Specialization could have a positive performance impact due to economies of scale in handling a particular type of cargo. Those that diversify could benefit from economies of scope and cost complementarities in cargo handling. Martinez-Budria et al. (1999) argue that Spanish port authorities with higher complexity in operations are more technically efficient than those with medium complexity, and ports with low levels of complexity achieve negative growth in efficiency over time. They also suggest that specialization leads to excess capacity, which could be better utilized in diversified seaports owing to the seasonality of specific cargo types.

The impact of specialization on technical efficiency of Spanish port authorities has been explicitly tested in Inglada and Coto-Millan (2010), Tovar and Wall (2017) and Hidalgo-Gallego et al. (2020). Tovar and Wall (2017) find a positive relationship between cargo concentration and technical efficiency. They also find that specialization of the larger Spanish ports in several outputs and the specialization of the smaller Spanish ports in a single output has a positive impact on technical efficiency. Moreover, they find that the specialization benefits of the larger Spanish ports are higher than those of smaller Spanish ports. In relation to cargo types, Inglada and Coto-Millan (2010) find that specialization in general cargo contributes to technological change improvements, specialization in passenger and liquid bulk cargo enhances scale efficiency, and overall technical efficiency and specialization in containerized cargo has a positive impact on total factor productivity growth. On the other hand, specialization in solid bulk handling has a negative impact on technological change of Spanish port authorities. Hidalgo-Gallego et al. (2020) find that increasing specialization in handling general cargo positively impacts technical efficiency but at a decreasing rate, meaning that the marginal positive impact of specialization in the handling of general cargo on technical efficiency could be low. Moreover, their results show that specialization in the handling of liquid bulk and solid bulk leads to lower technical efficiency. Based on the literature regarding the performance impact of specialization, we formulate the following hypothesis:

Hypothesis 1 (performance impact of specialization): Specialization has a positive impact on technical efficiency but at a decreasing rate.

Seaport management and operations have seen the emergence of various forms of public–private partnership arrangements ranging from build operate transfer (BOT) concession contracts, dedicated berth and terminal lease contracts, to simpler management contracts. Full privatization has also occurred, as in the case of the UK. To analyse the performance impact of public–private partnerships and privatization, Cullinane et al. (2005a) apply DEA to a data set of 30 container ports worldwide, spanning a time frame of 9 years from 1992 to 1999. They find no significant relationship between cross-sectional and inter-temporal efficiency and private participation, including full privatization. To the contrary, Cheon et al. (2010) conduct a Malmquist DEA for 98 global container ports for the years 1991 and 2004, finding that the total factor productivity of these ports is positively correlated with ownership restructuring, with a higher degree of private sector involvement. They argue that global terminal operators such as Hutchinson Port Holdings (HPH) and Dubai Ports World (DPW) have access to specialized technology, which implies government divestment from container port operations in order to enhance total factor productivity.

Country-specific performance impacts of private participation have been analysed in the case of Brazilian, US and Chinese seaports. Wanke and Barros (2015) show that a higher level of private participation at the major Brazilian seaports leads to significantly higher scale efficiency due to the operational flexibility of the private terminal operators. Wang et al. (2013) also show that landlord ports in the USA have a higher profit efficiency in comparison with operating ports. In their efficiency analysis of 21 Chinese container terminals, Yuen et al. (2013) find that a majority of foreign investment with a minority of Chinese controlling stake has significant positive impacts on technical efficiency. They argue that this is due to the specialization of the foreign investor complemented with the Chinese stakeholder's knowledge of the local upstream and downstream markets. Contrary to the results obtained by Yuen et al. (2013), Zheng and Lin (2015) analyse the efficiency of 16 Chinese port corporations and find that ports with a majority state ownership have higher cost efficiencies. They argue that this is because China is transitioning from a planned to a market economy. During this transition period, ports need state support for the provision of transportation infrastructure, and ports with a higher share of state involvement get preferential policies from the Chinese government. Our hypothesis regarding the performance impact of external stakeholder participation in seaport operations is as follows:

Hypothesis 2 (performance impact of external stakeholder participation): A higher degree of external stakeholder participation in seaport operations leads to higher technical efficiency.

As seaports are parts of complex trade networks, competition occurs at hierarchical levels (Verhoeff, 1981). In the extant literature, the impact of competition on performance has been analysed for regional inter-port competition between container ports globally (Oliviera and Cariou, 2015); regional inter-port competition between European container ports (Merkel, 2018); and inter- and intra-port competition among Chinese container terminals (Yuen et al., 2013). The Oliviera and Cariou (2015) results show a significant negative impact of inter-container port competition on efficiency between competitors located within a great circle distance of 400–800 km. Merkel's (2018) analysis of the European container ports shows a significantly higher technical efficiency for container ports locked in regional competition within a Euclidean distance of 300 km, hence proposing the promotion of competition between European container ports.

Yuen et al. (2013) obtain mixed results regarding the performance impacts of competition among container terminals in China. They show that inter- and intra-container port competition has positive impacts on technical efficiency, whereas inter-container terminal competition is shown to have significant negative impacts on efficiency growth. It is argued that the negative impact of inter-container terminal competition on the Malmquist DEA efficiency-growth estimates is due to the free rider problem and the late mover advantage. Trade-oriented regions invest heavily in port infrastructure, and incumbents incur significant costs in shaping the regional port-oriented supply chain, which may lead to over-investment. New entrants then free ride on the incumbents' investment without the need for additional investments in the region's port-based knowledge creation and supply chain orientation. As Indian seaports operate in a tiered governance framework which includes federally owned and regulated ports alongside local state-owned seaports, we hypothesize that the impact of competition will be as follows:

Hypothesis 3 (performance impact of competition): A higher level of competition between federal and state-owned seaports encourages improvements in technical efficiency.

With the advent of the landlord and private service seaport models that opened up the market for private participation, the open question is whether regional market power could impact cargo-handling charges and service quality levels. Estache et al. (2004) address the issue of potential market failure by suggesting that data envelopment analysis (DEA) could be employed in the economic regulation of seaports to ensure that the efficiency gains from port reforms lead to downward revisions in cargo-handling tariffs. Ferrari and Basta (2010) estimate the *x*-parameter in the price-cap incentive in regulatory mechanisms, as applied to Italian container terminals by employing DEA models. With regard to the regulation of competition *for* the market, terminal operating and cargo-handling companies might overbid for the rights to operate a terminal and then pass these costs on to the users by charging higher prices (Theys et al., 2010). As a result, regulation of competition *for* the market may be needed to prevent the bidding companies from overbidding. Our hypothesis with regard to the performance impact of regulation is as follows:

Hypothesis 4 (performance impact of regulation): (a) Tariff regulation by an independent or partly independent regulator is more efficiency inducing than internally regulated seaports.

(b) Regulation of competition for the market leads to optimal bidding by cargo-handling companies.

3.3. Seaport reform and governance in India

The Indian seaports were governed by a two-tiered framework wherein the federally owned seaports were under the jurisdiction of the central government in accordance with the Major Ports Trusts Act (1963), while the local state-owned seaports were under the jurisdiction of the respective state governments in accordance with the Indian Ports Act (1908). Currently, the only corporatized port is located in Kamarajar, according to the Companies Act (1956). Within the two-tiered governance framework, the non-economically regulated state seaports have increased their cargo share (Raghuram and Udayakumar, 2015), leading to a higher degree of competition between the state and federally owned seaports over time[5].

The Indian government introduced three seaport reform programmes over the last 15 years. The National Maritime Development Programme (NMDP) was introduced in 2005, with the dual objective of expanding capacity and modernizing the existing federal port infrastructure. The agenda included the deepening of channels, construction of new berths, procurement of modern cargo-handling equipment and improvement of hinterland road and rail connectivity. The investments were funded by the central government, the port's internal resources and private investors (MoS, 2005).

The Indian Maritime Agenda (IMA) 2010:2020 focused on improving port capacity, performance, and coastal and inland waterways shipping. The IMA report (MoS, 2011) required governance-related reforms including the corporatization of port trusts, implementation of the landlord port model and promotion of effective competition by revising the existing regulatory mechanism. In addition, establishment of a maritime finance corporation, a public–private partnership forum called the Indian Maritime Council, and state maritime boards were on the agenda. The passing of a new Indian Ports Act was also on the agenda.

[5] We note that the state-owned seaports are free to set charges based on market conditions and determine service quality based on agreements with shipping lines.

Under the Major Port Authorities Act (2015), the government granted greater autonomy to port trusts, with the intention of corporatizing them at a later date. Corporatization, in conjunction with the landlord seaport model, was intended to improve the performance of Indian seaports. The revenue share from concession contracts could be used by port authorities to partly fund seaport and maritime facilities, including the maintenance, innovation and modernization of common port facilities.

The latest program, the Sagarmala project (MoS, 2016), was intended to reduce logistics costs and to encourage port regionalization (Notteboom and Rodrigue, 2005). The initiative includes the setting up of manufacturing clusters around ports, port-based smart cities and coastal economic zones. Additional objectives included institutional improvements of the public–private partnerships and the development of agglomeration benefits by creating jobs for coastal communities.

For public–private partnerships, build, operate and transfer (BOT) contracts have been readily used to build additional terminals. BOT contracts are awarded to the concessionaire through competitive bidding in India. The bidding criteria include the license fee, revenue share, rent and cargo volume quoted, and the maximum net-present-value bidder wins the contract (Haralambides and Behrens, 2000). Upon the expiry of the concession period, the concessionaire shall handover the terminal to the port authority, and new bids will thereafter be invited. According to one of the Sagarmala reports (Vol. 3, MoS, 2016), private participation has been lower than anticipated. The report suggests that contracts have been excessively rigid by defining the type of cargo to be handled and by prohibiting bidding for the rights to operate a second terminal at the same seaport, which might, allegedly, inhibit economies of scale.

Encouraging competition has been addressed through economic regulation by a partly independent regulator called the Tariff Authority for Major Ports (TAMP). The regulator publishes guidelines to set tariff ceilings and to regulate the quality of service. The regulation has been cost-based. The first set of guidelines was published in 1998, according to which the operator was allowed a 20% return on equity over and above the project costs. In the same guidelines, the bids were allowed to pass through as operating costs, which could lead to higher cargo-handling charges to the port customer. To effectively regulate the competition *for* the market, vis à vis competition *in* the market[6], the guidelines published in 2003 created amendments such that only the bid of the second-highest bidder was allowed to pass through as operating costs. This pass-through of bidding costs was not valid after the operator started making profits. The next set of guidelines was published in 2005 (TAMP, 2005), according to which terminal operators were allowed a 15% rate of return on the capital rate base[7]. This change was implemented because a higher equity share in the previous two sets of guidelines would lead to higher cargo-handling rates. The TAMP (2008) guidelines introduced upfront tariff ceilings, aiming to prevent opportunistic behaviour by the regulator and annual tariff escalations. From 2013 (TAMP, 2013, 2015) onwards, performance incentives were also included in the regulatory guidelines. We evaluate the impact of these governance and reform programmes by modelling the seaport production process.

[6] Competition *for* the market may be implemented when direct competition is not possible, for example due to the size of required investments (e.g. in the electricity distribution market). Instead, firms bid for the right to serve the market for a specific timeframe. Competition *in* the market takes place after entry, wherein a firm competes with other firms serving the same or overlapping markets.

[7] The capitalization rate indicates the rate of return permitted as a function of the net income generated, divided by the terminal asset value.

3.4. Models and data

This section is organized into three subsections. Section 3.4.1 explains the DEA model which has been used in this research. Section 3.4.2 describes the variables and data which have been collected and analysed in the modelling approach. Section 3.4.3 describes the regression model, along with the variables and the data, which have been applied in a second-stage process to explain the results of the first-stage efficiency estimates.

3.4.1. Slacks-based measure of efficiency

Tone's (2001) variable returns-to-scale, slacks-based measure (SBM) was applied to measure relative performance because of many desirable properties, including units invariance[8]. SBM is non-oriented, allowing the modeller to assess slacks in both input and output variables, similar to that of the additive model (Charnes et al., 1985). Furthermore, the model is non-radial, permitting non-proportionate reduction and expansion rates for respective inputs and outputs. Finally, given the large differences in the sizes of the ports studied, a variable returns-to-scale model seemed the most appropriate. We construct a static inter-temporal frontier (Tulkens and van den Eeckaut, 1995) by including all seaport-year observations, because the unbalanced panel data set prevents us from applying Malmquist DEA. We then test the impact of exogenous factors on seaport performance by applying fixed effects regression models in a second stage.

3.4.2. Variables for the SBM

The review of the port production process leads us to identify eight variables to be included in the DEA models. Table 3.1 provides a description of these variables, including their descriptive statistics. The data were collected from the annual publication of the Indian Ports Association (IPA, 1996–2016), which provides annual data. After accounting for missing values, we created an unbalanced panel data set of 230 observations.

On the input side, we include measures of capital, variable costs[9], full-time equivalent port authority staff and a proxy for cargo-handling labour. With regard to capital, the IPA publications contain information on the depreciation of port authority assets and its annual financial and miscellaneous expenditures. As the depreciation of port authority assets represents an accounting proxy for capital input, we add this measure to the financial and miscellaneous expenditures, which represent a proxy of the annual inflow of investment into a certain port. The capital measure is a proxy because the net book value of assets is not published. We also include the number of berths, which is a physical measure of capital. The variable costs include the operating expenditure of the port authority such as inventory, office and administration, operation and maintenance, security, medical and other expenses. The

[8] The model was run using the additiveDEA package in R (Soteriades, 2017).

[9] Ports provide services such as mooring, pilotage, berthing, cargo handling and storage (Meersman et al., 2014), and they incur both fixed and variable costs in providing these services. According to Bisevac et al. (2019), the variable costs incurred include expenditure on fuel for the operation of cargo-handling equipment, maintenance, rental charges of equipment and wages. At Indian seaports, these variable costs are broadly categorized as stores, office and administrative, operation and maintenance, security, medical and other expenditure. In 2015, stores accounted for 5.56%, office and administrative expenditure accounted for 5.53%, operation and maintenance accounted for 41.97%, security accounted for 10.19%, medical expenditure accounted for 6.23% and other expenditure accounted for 30.52% of the variable costs incurred at all major Indian seaports. Wages are also a part of the variable costs, but as we have two other inputs that account for labour, we do not include wages in computing the variable costs.

mean of the capital measure is only slightly higher than the variable costs. This is due to the fact that port asset depreciation is generally spread over a long period. Labour inputs comprise the number of non-cargo-handling, port authority officers and a proxy for the stevedore gangs[10]. The stevedore gang is a proxy because some port authorities employ the labourers directly whilst others outsource the cargo-handling activity. Stevedore gangs are assumed to be a direct function of the number of mobile, wharf, quay and yard cranes, thus assuming that cranes and cargo-handling employees are used in fixed proportions.

We include three variables on the output side: two cargo-related measures estimating the total number of vessels handled[11] and the total volume of cargo handled in millions of tonnes annually. Both variables are included because the vessels handled reflect berth side operations and the cargo handled reflects yard side operations. Berth side operations involve a higher share of investment in capital, including the construction of berths, dredging and equipment such as cranes. Yard side operations involve a higher share of variable costs, and cargo handled is a partial indicator of the output generated accordingly. Furthermore, vessel sizes have been increasing, and the inclusion of cargo handled provides a clearer picture of this impact on seaport efficiency over time for this panel data set. The two cargo-related variables contain information on all cargo categories, including dry bulk, liquid bulk, general cargo and containers handled. Finally, as shipping lines have to pay both vessel and cargo-handling fees, including both vessels handled and cargo handled as outputs represents the fee structure charged to the shipping lines (Button and Kramberger, 2015). The third output is a measure of the quality of service and is defined as the reciprocal of the average turnaround time of vessels. This variable is used as an output since it is a result of the production process and ensures that we correctly attempt to optimize service quality (Scheel, 2001). The wide range of this variable, as shown by the minimum and maximum values in Table 3.1, denotes the significant difference in the quality of service offered at the ports in our data set.

[10] The capital and labour measures are positively correlated, with a correlation of 0.51 between capital and non-cargo-handling labour and a correlation of 0.28 between capital and cargo-handling labour. Despite the positive correlation, we include capital and labour measures as inputs in the DEA models because the literature review revealed that both measures are required to get a complete representation of the production process of seaports. Moreover, as capital and labour are substitutes, the decision of the choice of composition of the inputs decides the capital intensity of the seaport.

[11] The berth occupancy rate could be used as a service-quality-related output instead of the total vessels handled. However, due to the practical difficulties of aggregating berth-level occupancy rates for each port, we have instead opted to use the total vessels handled as an output.

Variable	Factor	Description	Unit	Mean	Std. Dev.	Min.	Max.
Inputs	Capital	Depreciation of the port authority's assets plus the finance and miscellaneous expenditure	Rs. crore[a,b]	94.72	83.71	9.41	397.91
	Capital	Number of berths	Count	21.36	13.17	6	56
	Variable costs	Operating expenditure minus the depreciation of the port authority's assets minus the salaries and wages	Rs. crore	90.75	76.07	5.36	404.57
	Labour	Number of non-cargo-handling officers and workers	Count	4,038.80	3,782.69	686	20,019
	Capital/cargo-handling labour proxy	Number of cranes	Count	30.16	29.19	1	147
	Vessels	Total number of vessels handled	Count	1,668.15	747.49	414	3,681

Variable	Factor	Description	Unit	Mean	Std. Dev.	Min.	Max.
Outputs	Cargo	Total volume of cargo handled	Million tonnes	36.94	19.31	6.87	100.05
	Quality of service	Reciprocal of the average turnaround time	$Days^{-1}$	0.27	0.11	0.07	0.63

Table 3.1: Descriptive statistics of the variables for the DEA

[a] All monetary measures are in crores of rupees, which have been adjusted with the wholesale price index (WPI) with financial year 1995-1996 as the base year in order to account for inflation

[b] One crore equals 10 million

Figure 3.1 depicts an index constructed over the annual averages of the eight variables and normalized for base year 1995. The trends are indicative of the rate of change per variable over time. All variables, excluding labour inputs, depict a net positive slope in the trend. As the ports appeared to be highly overstaffed in the early years, with as many as 20,019 port authority employees (see Table 3.1), the reform programmes focused on reducing labour costs. A 65% average reduction in port authority staff was achieved by 2015, suggesting that the reform programs may have achieved some of their goals. Modernization programs focused on equipping ports with better technology, which reduced the number of cranes needed by an average of 25% by 2015. These reductions have occurred despite an increase of 170% in cargo handled and a 65% increase in vessels served. The variable depicting the highest fluctuations is the measure of capital. Whilst depreciation is fairly stable over time, the finance and miscellaneous expenditures vary substantially over time and across seaports, primarily based on port authority forecasts of demand for specific seaport infrastructure. The variable costs show a more stable rate of increase of 100% over the 21-year period. On the output side, cargo handled shows a higher rate of growth compared with vessels served, which confirms that the size of vessels has been increasing over time. The decline after 2010 in the growth rate of cargo and vessels handled is attributed to the global economic recession of 2009. Finally, the quality of service initially improved, followed by a decline after 2002. Quality levels started to improve after the introduction of the Indian Maritime Agenda in 2010 such that the 2002 levels were again achieved in 2015.

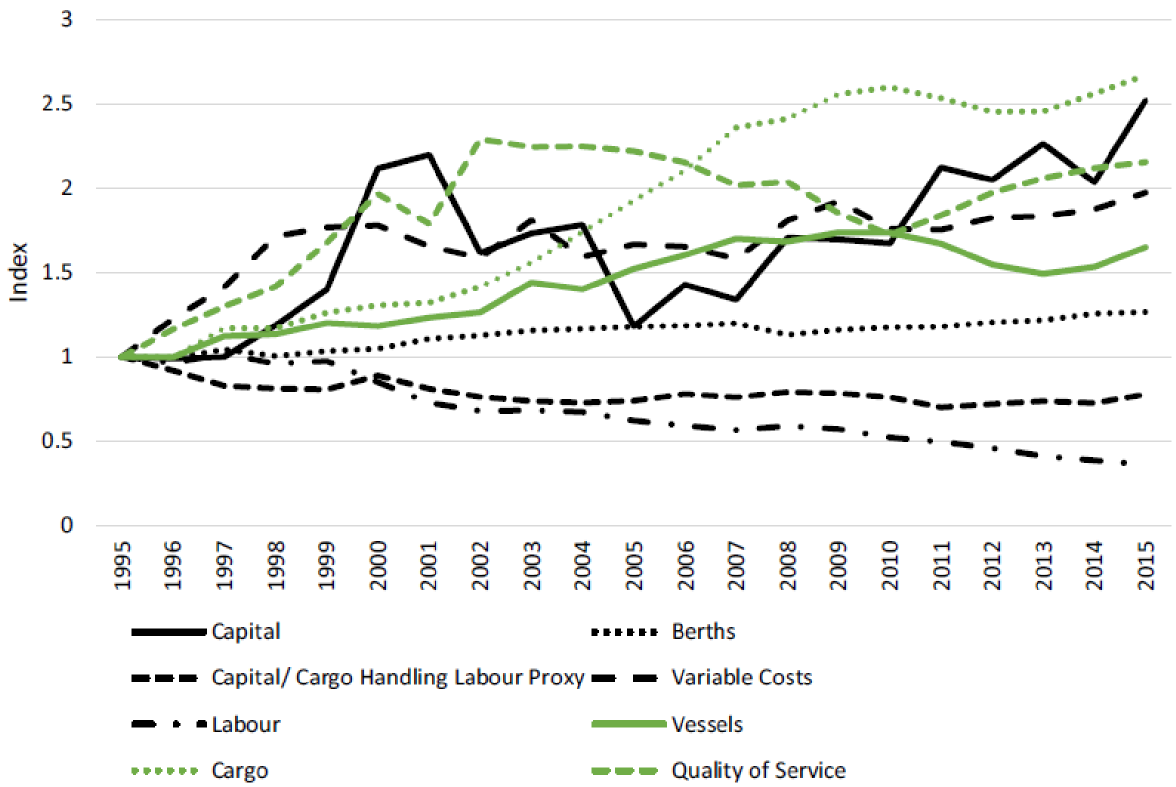

Figure 3.1: Trend of inputs and outputs

We test three DEA models in this research. Model A contains three inputs, namely capital, variable costs and port authority labour levels, and two outputs, the vessels served and cargo handled. Model B includes all model A variables and the service quality indicator. The third model is a principal components analysis and data envelopment analysis (PCA-DEA) model

(Adler and Golany, 2001). The PCA-DEA model has all outputs included in model B and the variable cost input. The second input is the first principal component of the monetary measure of capital and the number or berths, which explains 85% of the variance in the data. The third input is the first principal component of the port authority labour and the number of cranes, which is a proxy for the cargo-handling labour, and this principal component explains 72% of the variance in the data.

3.4.3. Second-stage regression

Our aim is to quantify the impact of specialization and governance-related factors on seaport performance. We do this in the second stage of our analysis. Our seaports fixed effects regression model[12] is as follows:

$$Eff_{it} = \alpha + \beta_1 Spec_{it} + \beta_2 O_{it} + \beta_3 CompState_{it} + \beta_4 CompCoa_{it} + \beta_5 CompOppCoa_{it} + \beta_6 Reg_t + \beta_7 Time_t + \mu_i + \epsilon_{it}$$

where Eff_{it} is the efficiency estimate of seaport i in year t; α is the time-invariant intercept; the βs are the estimated coefficients of the independent governance-related variables; μ_i is the time-invariant error component of seaport i; and ϵ_{it} is the independent and identically distributed (IID) error component of seaport i in period t. We test three regression models covering all DEA estimates (models A, B and PCA-DEA).

Specialization and diversification strategies of seaports are a function of the derived demand that seaports face from their respective catchment areas. We derive an absolute measure of specialization using the Keeble and Hauser (1971) HHI, which is an economic measure of the specialization at the seaports. We derive the Keeble and Hauser specialization measures by computing the square root of the sum of squares of the shares per cargo category. This gives us an absolute measure of specialization, with one value for each seaport-year observation. The values range from 0 to 1, with 1 signifying full specialization at the seaport, namely a single cargo type. The reason for applying the HHI is that this is a parsimonious measure satisfying the axioms of anonymity, progressive transfers, bounds, decomposability, splitting and merging of cargo categories handled, and the inclusion of zeroes in the absence of the handling of specific cargo categories (Palan, 2010). Specialization, $Spec_i$, in the models we test, is defined as follows:

$$Spec_i = \sqrt{\sum_{k=1}^{4} (s_i^k)^2}$$

where $s_i^k = \frac{x_i^k}{\sum_{k=1}^{4} x_i^k}$. x_i^k is the volume of a specific category of cargo handled where k = 1 is the volume of dry bulk cargo handled, k = 2 liquid bulk handled, k = 3 break-bulk cargo handled and k = 4 container cargo handled[13]. We calculate this measure for all seaports over the 21 years of analysis. By squaring the share of a particular type of cargo category, the HHI places a higher emphasis on those cargo types in which a seaport specializes. We run another set of

[12] We ran the open source plm package in R (Croissant and Millo, 2008).
[13] Each cargo category has its own terminal. For example, K = 2 would mean a liquid bulk terminal. This is mostly the case, except for multi-purpose terminals. We have aggregated this information at the level of the port because we do not have sufficient information at the level of each individual terminal to perform a disaggregated analysis.

regression models with specialization as a categorical variable by splitting the Keeble and Hauser HHI into five levels, namely below 60%, between 60% and 70%, between 70% and 80%, between 80% and 90% and above 90% specialization. This has been done to test whether increasing specialization impacts performance at a decreasing rate.

With regard to particular cargo categories, in absolute terms, dry bulk and liquid bulk have the highest shares of cargo handled. However, over time, these shares decline from around 45% of dry bulk cargo to around 37%. The share of liquid bulk went up to 41% in 1999, after which it declined to around 37%. Break-bulk cargo handled has the lowest share, which declined to around 4%. Container cargo has the highest rate of increase, and its share in the total volume of cargo handled has grown from 10% to 22% over the timeframe.

We calculate the ownership measure, O_{it} by including information on the number of berths that are operating with external stakeholder participation out of the total number of berths of the seaport. This measure thus contains information on dedicated berth, management and concession contracts that the external stakeholders have signed with a port authority. The dedicated berth operators in the country are mostly from the petroleum, chemical, fertilizer and mining sectors. For example, at the Jawaharlal Nehru Port Trust, the loading and unloading of the liquid bulk is handled by the port authority, while the storage operations of the liquid cargo are handled by private operators. For containerized cargo, port authorities sign standard concession contracts with terminal operators, of a typical duration of around 30 years. After creating this measure, we define three levels: (i) between 0% and 33%, (ii) between 33% and 66%, and (iii) above 66% stakeholder participation at the level of the berth. We use a categorical measure to give policy suggestions on the degree of public–private partnership which may be conducive to seaport performance. A level below 33% of stakeholder participation is indicative of a public service seaport. A landlord seaport with BOT contracts would have either between 33% and 66% or above 66% stakeholder involvement, depending on the degree to which seaport services have been contracted out to the private sector. The second and third categories compare the performance impact of varying levels of stakeholder involvement in seaport operations.

Market entry by state seaports governed by state maritime boards has increased competition intensity. The existence of an uneven governance and regulatory framework necessitates the measurement of the impact of competition on efficiency. Since location is one of the most relevant determinants of port choice (see review of Martínez Moya and Feo Valero, 2017), we develop a competition measure based on distance to and size of competing ports. Given a seaport *i*, where *n* is the number of state seaports operating in the predefined geographical zone, and c is the number of state seaports operating outside the predefined geographical zone, our measure of competition is defined as follows:

$$Comp_i = \sum_{j=1}^{n-i-c} \frac{CarHan_j}{d_{ij}}$$

where $CarHan_j$ is the cargo handled by the state seaport j. $n - i - c$ indicates that the major seaports and state seaports outside the predefined geographical zone have been excluded from the calculation of the respective measure of competition. The above-defined competition measure has been calculated for each seaport and for each year from 1995 to 2015. This is a distance-weighted competition measure that is related to the concept of accessibility. It is the distance-discounted size of neighbouring ports. The larger this measure, the stronger the competition between a port and its neighbours[14]. The distance between ports, d_{ij}, is measured using the great circle distance between major-state seaport pairs. The distance is the weighting factor that takes into account the fact that competition intensity declines with increasing distance between seaports owing to a reduction in the overlap of hinterlands. We have also run a set of regressions where we use the distance along the coast between major-state seaport pairs, but we report only the results which are significant.

The geographical zones we use are the state, the coast and the opposite coast. As a result, we obtain three competition-related variables: $CompState_i$, $CompCoa_i$ and $CompOppCoa_i$. The first variable measures competition within a state. The second variable measures competition along the coast by excluding the ports that operate in the same state and the ports that operate along the opposite coast. The third variable measures the competition with state seaports from the opposite coast by excluding the ports operating within the same state as well as the ports operating along the same coast. The reason for separately measuring competition within the state and along the coast is that ports within the same state operate under a similar governance framework. As a result, the characteristics of the competition that a major seaport faces from a set of state ports from within the state would be similar in nature, due to the existence of common governance and policy framework for local ports within a state. The three competition variables are adjusted with the respective sample standard deviations to account for the wide dispersion in the values of these variables. To estimate the performance impact of regulatory changes over time, we create dummy variables covering the specific timeframes between each of the guidelines, creating seven dummies respectively. Finally, we also include year dummies, $Time_t$.

Variable	**Mean**	**Std. Dev.**	**Min.**	**Max.**
Specialization	0.73	0.11	0.54	0.96
Competition within state	0.45	1	0	5.61
Competition along coast	0.74	1	0	4.53
Competition from opposite coast	0.70	1	0	3.82

Table 3.2: Descriptive statistics of continuous independent variables

Table 3.2 presents the descriptive statistics for the continuous variables in the regressions. As regards specialization, the mean value of 0.73 indicates that seaports are pursuing a specialization strategy rather than striving to diversify. Concerning competition, some ports in states such as Goa and West Bengal face no competition from state seaports; hence, minimum values are zero.

Since many state seaports along the east coast entered the market after 1999, the minimum value for competition along the coast, and with the opposite coast, is also zero. The mean value for competition within the state is lower than that of competition along the coast, because the

[14] For instance, Desmet et al. (2020) use it as a measure of competition among cities. In gravity estimates of trade, a term called *multilateral resistance* measures the size of all alternative destinations that may divert trade to these destinations. It depends on size and distance or trade costs. The concept of multilateral resistance was first suggested by Anderson and van Wincoop (2004).

number of state ports operating along the coast is higher than those operating within an individual state, with the exception of Gujarat and Maharashtra. The same line of reasoning explains the lower mean value for competition within a state, compared with the competition with the opposite coast. Weighting by distance implies that the mean value of competition along the coast is higher than that of competition with the opposite coast. In Gujarat and Maharashtra, there is a higher degree of competition because there are several state seaports. Therefore, we expect competition to have a positive impact on technical efficiency. In the rest of the states, with a lower number of state seaports, we expect lower competition to have a negative impact on technical efficiency. For example, JNPT, which is in Maharashtra, has 22 cargo-handling state seaports within a distance of 300 km and 22 cargo handling state seaports within a distance of between 300 and 700 km. Meanwhile, Haldia, which is in West Bengal, has only one cargo-handling state seaport within a distance of 300 km and one cargo-handling state seaport within a distance of between 300 and 700 km. Appendix 3.A contains information on the regulation and ownership variables.

3.5. Results

The results we obtain show that the Indian seaports have significant scope for improvement. Ports which specialize benefit from economies of scale, which leads to better performance. External stakeholder participation improves the performance of the major seaports. Competition between major and state seaports in a tiered governance framework has negative impacts on the performance of the major seaports. Finally, cost-based regulation is preferred over internal regulation by the port authority. These results are further elaborated in the upcoming sub-sections. Section 3.5.1 discusses the results of the slacks-based measure of efficiency, and Section 3.5.2 discusses the results of the second-stage regression models.

3.5.1. Slacks-based measure of efficiency

Figure 3.2 depicts the box plots of the SBM efficiency estimates of the 11 seaports, for the 21-year time duration considered. These measures of relative technical efficiency are based on the assumption that the ports minimize the relative excess in inputs and maximize the relative shortfall in outputs. We observe a high correlation in efficiency scores of the three DEA models. Appendix 3.B contains the DEA scores for all seaports for the 21 years.

Model A has a higher discriminatory power than model B because *quality of service* is not included. This is reflected in the lower mean score for technical efficiency. Ports that get a better ranking in model A, in comparison with model B, are those that have a relatively poorer service quality. This may be due to the presence of capacity constraints that can lead to congestion at the seaports, resulting in higher average turnaround times due to decreasing returns to scale on investment. This could also be due to the size and type of vessels handled. If a seaport handles larger vessels on average, this could result in longer turnaround times. Finally, ports which do not invest heavily in providing services of superior quality will get a higher ranking in model A. These could be some of the reasons why ports such as Mumbai, Paradip, Vizag and Kandla are offering relatively poorer service quality in comparison with the other ports.

Moreover, ports that achieve a higher ranking in model B, in comparison with the PCA-DEA model, are those that have a relative excess of cranes, cargo-handling employees or berths. One reason may be that such ports are specializing in handling containers, hence the high amount of crane usage. Secondly, this may also be due to the usage of outdated technology, which leads to a lower performance score in the PCA-DEA model when in comparison with model B. With regard to overall performance, ports such as Tuticorin, Kandla, NMPT and JNPT are the best performers, while ports such as Mumbai, Kolkata Port Trust, Chennai, Mormugao, Paradip, Cochin and Vizag have significant scope for improvement.

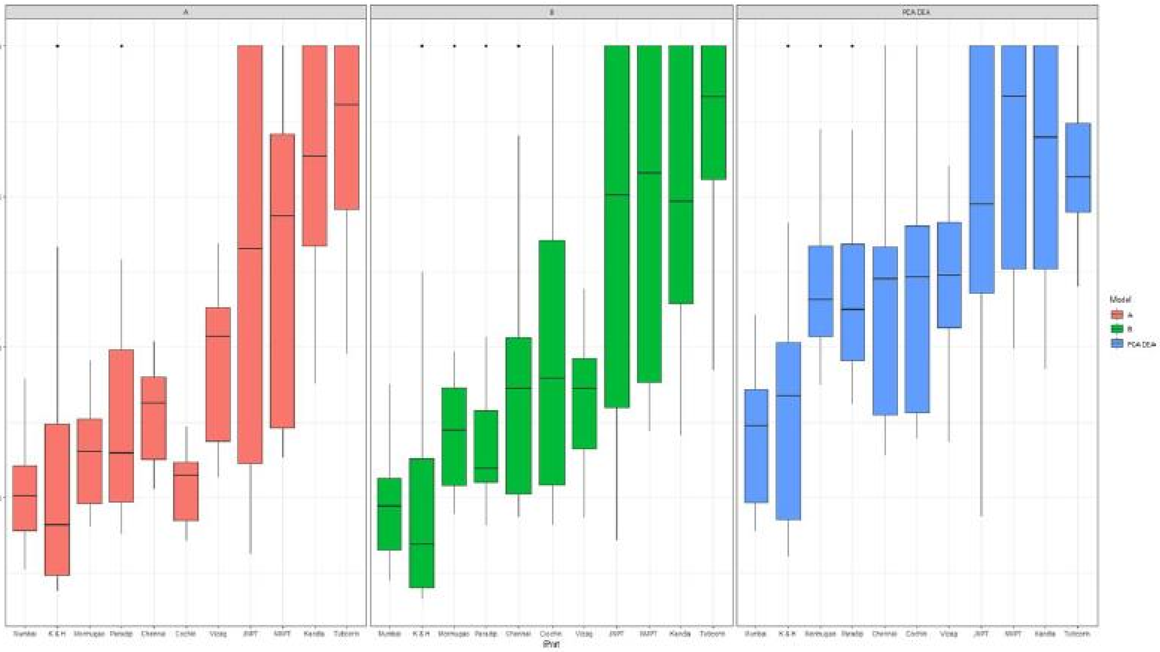

Figure 3.2: Slacks-based measure of efficiency

Figure 3.3 shows the trend in the average annual technical efficiency in models A, B and PCA-DEA. The results should be interpreted as the technical efficiency trend with respect to a static efficiency frontier. All three models show that there are two phases of decline and improvement in technical efficiency across all seaports. The first phase of decline occurred till 1999, after which there is an improvement until 2007. The second, shorter phase of decline continued until the end of 2012, after which performance improves. The first phase of decline in performance has been addressed by the Indian Ministry of Shipping by introducing the National Maritime Development Programme in 2005. Thereafter, even though the second reform programme, namely the Indian Maritime Agenda, was introduced in 2010, the second phase of decline can be attributed to macroeconomic shocks such as the economic recession, the illegal mining of iron ore in India, and the contraction of Chinese imports of Indian iron ore. Fitting a trend line for performance across the three models reveals that the average annual performance gradually increased from around 45% average efficiency in 1995 to around 75% in 2015.

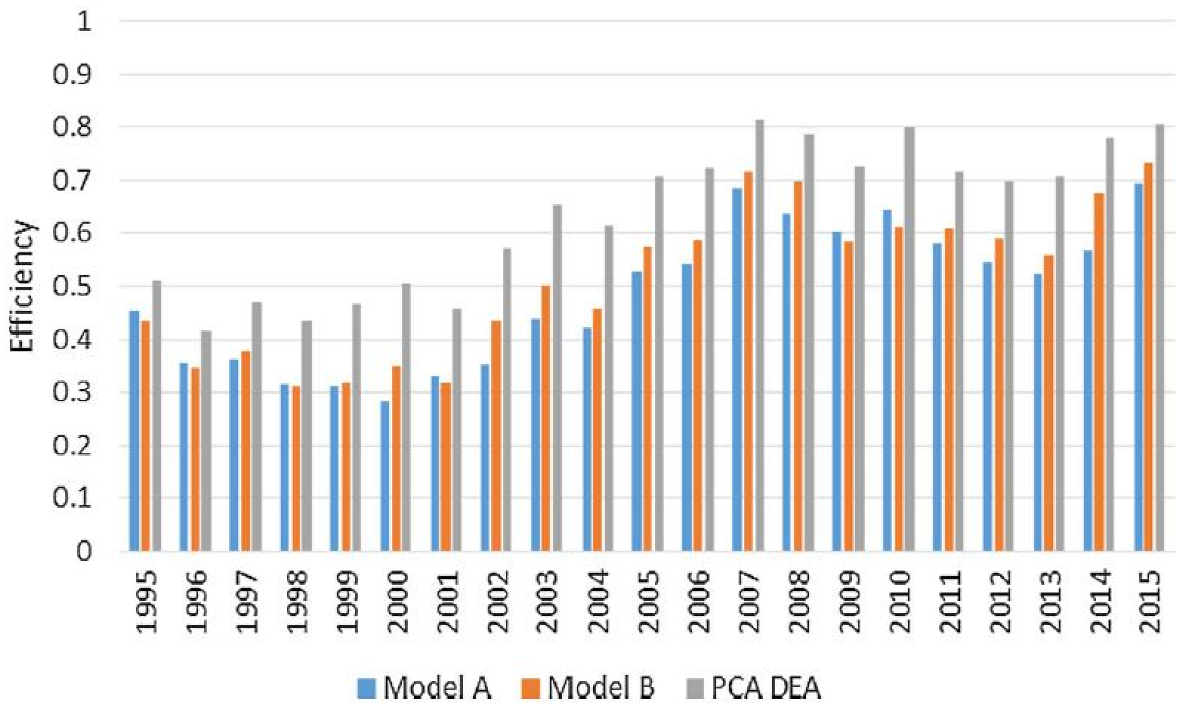

Figure 3.3: Average annual port efficiencies

3.5.2. Second stage regression

Table 3.3 presents the results of the regression models. The coefficient for the absolute measure of specialization has a significant positive impact on performance. Moreover, specialization has the highest positive impact among all variables, which suggests that economies of scale are very important for efficient use of resources. As the coefficient tends to be higher when service quality is not included in the first stage (Model A), the rate of improvement in service quality is lower than the rate of increase of cargo-related outputs when seaports pursue specialization strategies. The results obtained here are broadly in line with those obtained by Tovar and Wall (2017). With regard to the categorical specialization variable, Model A results show that specialization impacts performance with an increasing rate for specialization levels of up to 90%, after which the magnitude of the impact decreases. Similar results are obtained for the performance impact of specialization in Model B. The results for the PCA-DEA model show that the positive performance impact of specialization is sustained with an increasing rate for specialization levels of more than 90% as well. As a result, we only partly accept our first hypothesis, which states that specialization has a positive impact on technical efficiency but at a decreasing rate.

Regarding external stakeholder participation, the higher the participation, the higher the level of relative efficiency estimates. The higher magnitude of the coefficient for external stakeholder participation above the level of 66% suggests that the landlord seaport model with port authorities in an administrative role while contracting out most seaport operations to third parties is conducive to better seaport performance. These results confirm our second hypothesis, that a higher degree of external stakeholder participation in seaport operations leads to higher technical efficiency.

	Model A	Model B	PCA DEA	Model A	Model B	PCA DEA
Specialization (KH HHI)	1.070***	0.792***	0.707***			
	(0.237)	(0.302)	(0.254)			
Spec. Below 60%				0.069	0.033	0.068
				(0.047)	(0.061)	(0.051)
Spec. 60 to 70%					Base Case	
Spec. 70 to 80%				0.082**	0.104**	0.107***
				(0.033)	(0.043)	(0.036)
Spec. 80 to 90%				0.221***	0.156***	0.106**
				(0.044)	(0.057)	(0.048)
Spec. Above 90%				0.159***	0.118	0.144**
				(0.057)	(0.074)	(0.062)
Ext. Own. Below 33%			Base Case			
Ext. Own. 33 to 66%	0.101*	0.207***	0.078	0.148**	0.245***	0.109*
	(0.059)	(0.075)	(0.063)	(0.058)	(0.076)	(0.063)
Ext. Own Above 66%	0.201**	0.450***	0.237**	0.243***	0.486***	0.259***
	(0.087)	(0.111)	(0.093)	(0.087)	(0.112)	(0.094)
Competition State	-0.041***	-0.041**	-0.030*	-0.025	-0.027	-0.014
	(0.016)	(0.020)	(0.017)	(0.016)	(0.021)	(0.017)
Competition Coast	-0.076**	-0.079*	-0.055	-0.061*	-0.057	-0.016
	(0.033)	(0.042)	(0.035)	(0.033)	(0.043)	(0.036)
Competition Opp. Coast	-0.022	-0.047	-0.010	-0.026	-0.040	0.003
	(0.024)	(0.031)	(0.026)	(0.025)	(0.032)	(0.027)
Internal Regulation	-0.100*	-0.132*	-0.174***	-0.104*	-0.119	-0.135**
	(0.060)	(0.076)	(0.064)	(0.061)	(0.079)	(0.066)
TAMP 1998	-0.140**	-0.192**	-0.178***	-0.154***	-0.188**	-0.150**
	(0.058)	(0.074)	(0.062)	(0.059)	(0.076)	(0.064)
TAMP 2003			Base Case			
TAMP 2005	0.278***	0.271***	0.210***	0.256***	0.242***	0.165***
	(0.057)	(0.073)	(0.061)	(0.057)	(0.075)	(0.062)
TAMP 2008	0.242***	0.247***	0.159**	0.194***	0.188**	0.085
	(0.073)	(0.093)	(0.078)	(0.072)	(0.094)	(0.078)
TAMP 2013	0.320***	0.401***	0.282***	0.267***	0.325***	0.181*
	(0.090)	(0.115)	(0.097)	(0.091)	(0.118)	(0.098)
TAMP 2015	0.440***	0.450***	0.303***	0.382***	0.376***	0.208**
	(0.090)	(0.115)	(0.096)	(0.089)	(0.116)	(0.097)
Observations	230	230	230	230	230	230
Time Effects	Yes	Yes	Yes	Yes	Yes	Yes
R^2	0.575	0.491	0.545	0.594	0.497	0.553
Adjusted R^2	0.496	0.396	0.460	0.510	0.394	0.462
F Statistic	10.059***	7.165***	8.890***	9.567***	6.483***	8.116***
	(df=26; 193)	(df=26; 193)	(df=26; 193)	(df=29; 190)	(df=29; 190)	(df=29; 190)
Note:						*p<0.1; **p<0.05; ***p<0.01

Table 3.3: Seaports fixed effects regression results

Interestingly, competition appears to harm the performance of the major seaports owing to the significant negative coefficients obtained in Model A. The results reveal that competition along the coast has a higher negative impact on the performance of the major seaports than competition within a state. This may be due to the fact that seaports have large catchment areas that present a higher likelihood of overlap. This also indicates that there is potential for substitution between seaports. These results are in line with the results presented by Oliviera and Cariou (2015). They show that competition has a negative impact on technical efficiency of container ports when competition arises from container ports that are at a distance of between 400 and 800 km to each other. But in contrast to their results, our results show that local competition originating from within the state also negatively affects technical efficiency of the seaports. As a result, we observe that reform and modernization programmes have not impacted sufficiently the major seaports in order to be able to effectively compete with the state seaports. Nevertheless, coastal competition does not have a significant negative impact on performance in Model B and the PCA-DEA. This would mean that the seaports are offering a better quality of service in anticipation of higher coastal competition from the state seaports. The least important form of competition draws from the opposite coast, which is insignificant. This is likely due to the distances involved and the poor road and rail infrastructure within India. We hence reject our null hypothesis, that a higher level of competition between the state and federal seaports leads to a higher technical efficiency of the federal seaports.

Although the competition-related results show a negative impact on the technical efficiency of federal seaports, the increasing degree of competition might have an overall positive impact on the technical efficiency of the system of seaports in the country, which is inclusive of both the federal and the state seaports. This is what has been shown by Merkel (2018) in the case of European container ports. These findings are also a part of the results obtained by Yuen et al. (2013) in the case of Chinese container ports. Our results show that, within the two-tiered governance framework, the federal seaports are not able to effectively react to competition that they face from the state seaports.

With regard to regulation, the modified TAMP 1998 guidelines are taken as the base case. We observe that internal regulation by the port authority has a negative impact on performance relative to the base case. Next, the TAMP 1998 guidelines did not take competition *for* the market into account in the design of the bidding process. Our results show that this also has a significant negative performance impact relative to the base case. Subsequent tariff guidelines introduced by TAMP show significant positive performance impacts relative to the base case in all regression models. Shifting regulation from the return-on-equity to the return-on-capital employed has had significant positive performance impacts. This is because a higher equity share in the previous two sets of guidelines would imply higher rates for cargo-handling services. The upfront fixation of tariffs also has a significant positive performance impact as it prevents opportunistic behaviour by the regulator. The inclusion of performance terms in determining the subsequent year's cargo and vessel handling charges has a positive performance impact as it encourages the terminal operators to offer a high service quality. The indexation of rates to the wholesale price index has also had a positive impact on efficiency relative to the base case as it takes inflation into account in the regulatory mechanism. These results confirm our fourth set of hypotheses, that tariff regulation by an independent or partly independent regulator is more efficiency inducing than when seaports are internally regulated by the port authority and regulation of competition *for* the market leads to optimal bids being offered by cargo handling companies to the port authority. To separate the regulation-related categorical variables from time-related exogenous factors, we included time dummies. The vast majority of the time dummies are not significant in our second-stage regression models. Therefore, we do not display them in Table 3.3.

3.6. Conclusions and future directions

In this paper, we estimate the impact of specialization and governance-related factors on the performance of the ports of India based on a two-stage model. We find that ports such as Tuticorin, Kandla, JNPT and NMPT achieve relatively higher average efficiency scores. Indeed, during the 21-year time period analysed, the average efficiency estimates have increased from around 45% to about 75%, which are all explained by the contextual variables. It becomes clear that further reform programmes should focus on the modernization of major seaports. Specialization has the highest significant positive impact on seaport performance, highlighting the importance of economies of scale. As the Sagarmala project[15] aims at port-facilitated industrialization, the Indian Ministry of Shipping could work on regionalization strategies that consider the performance benefits of seaport specialization.

Concerning the ownership structure, our results show that external stakeholder participation improves technical efficiency. The landlord seaport model not only reduces the public sector budget demands, but also improves seaport performance. As a result, the environment ought to be made conducive to public–private partnerships, whereby terminal operators need to be provided with an environment that deems concession contracts viable over the duration of the project.

The competition results of our analysis indicate that competition from state ports has a significantly negative impact on the performance of the federal seaports within a state as well as along the coast. It would be helpful if common governance, institutional and regulatory frameworks were applied to all seaports. This may promote effective competition among all the seaports in the country, thereby further improving performance.

As the landlord seaport model leads to market entry by firms with a profit maximization objective, market power needs to be regulated. Our results show that TAMP oversight has had an overall positive impact on performance. We conclude that cost-based regulation by an independent regulator is more performance inducing than internal regulation. Moreover, to avoid excessive quotes at the bidding stage, the introduction of regulation of competition *for* the market has had significant positive impacts on performance. The upfront tariff-fixation policy and the inclusion of performance terms in determining the scale of rates for subsequent tariff periods have also had a significant positive impact on performance.

We also suggest that, alongside an independent regulator, it is necessary to collect data for benchmarking. This may help prevent market power abuse, guarantee superior services to the port customer, and promote the long-term viability of seaport stakeholder investment. Benchmarking could contribute to the estimation of rates, performance standards and tariff guidelines. As partial indicators have been used to analyse performance, the forum of regulators

[15] The Sagarmala project intends to reduce logistics costs and encourage port regionalization. The initiative includes the setting up of manufacturing clusters around ports, port-based smart cities and coastal economic zones. Additional objectives include institutional improvements for public–private partnerships and the development of agglomeration benefits by creating jobs for coastal communities.

should be encouraged to apply methods such as total factor productivity, data envelopment analysis or stochastic frontier analysis to measure the performance at the level of the port, port authority and terminal.

As this research estimates technical efficiency, future research will have to focus on estimating cost efficiency of the Indian seaports. Benchmarking at the level of the terminal, inclusion of state-governed seaports in the data sets, and comparison of the performance of Indian seaports to the performance of international seaports are also venues for further research. This paper uses DEA to estimate efficiency. Future research could use other methods such as stochastic frontier analysis (SFA) and total factor productivity (TFP). It should also consider port-generated externalities. Finally, the impacts of improved port performance on the surrounding regions will also have to be studied.

Appendix 3.A. Number of observations within categories of categorical independent variables

Regulation	**Number of Observations**
Internal Regulation	32
TAMP 1998	55
TAMP 2003	22
TAMP 2005	33
TAMP 2008	55
TAMP 2013	22
TAMP 2015	11
Ownership	**Number of Observations**
Below 33%	171
33 to 66%	54
Above 66%	5
Specialization	**Number of Observations**
Below 60%	19
60 to 70%	83
70 to 80%	69
80 to 90%	35
Above 90%	24

Appendix 3.B. Inter-temporal DEA results

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Chapter 4

The impact of governance on technical efficiency of container ports[16]

Abstract

This research analyses the impact of governance-related factors including ownership, competition and regulation on the technical efficiency of container ports in the Far East and Asian regions. Using stochastic frontier analysis, we explicitly study the interactions between the levels of privatization and hinterland or transshipment competition, with the type of economic regulators involved. The findings suggest that independent regulators or port authorities encourage significantly higher technical efficiency compared to unregulated ports and government ministry regulated ports. Furthermore, the technical efficiency of majority private ports is significantly higher than minority private ports. Transshipment competition is also shown to positively impact the technical efficiency of container ports. On the other hand, the independence of the economic regulator is more important for technical efficiency than hinterland competition. Policymakers should ensure the independence of the regulator, encourage privatization of the operations and avoid excessive entry in order to promote the technical efficiency of container ports which in turn will strengthen global supply chains.

***Keywords*:** container ports, stochastic frontier analysis, technical efficiency, governance, ownership, competition, economic regulation

4.1. Introduction

The COVID-19 pandemic has resulted in serious congestion at many of the world's largest ports which has led to global supply chains experiencing a significant amount of delays. This has been caused by a stockpiling of freight and containers at seaport terminals and vessels being stuck in long queues awaiting access to berths at the seaports. In many cases, vessels and trucks are diverting their goods to nearby ports where congestion and delays are less severe. Gui et al. (2022) find that the major factors causing congestion and delays at seaports during the COVID-19 pandemic are an interruption of railway and barge services, a shortage of skilled labour at ports and a shortage of truck drivers and drayage trucks. Komaromi et al. (2022) find that the port centred supply chain crisis caused during the COVID-19 pandemic has resulted in port tariffs increasing anywhere in between 0.9 to 3.1%. They also find that delays caused by the crisis surpassed 1.5 days on average which is roughly a 25% increase in global travel times. These figures highlight the importance of seaports and their efficiency in mitigating the adverse consequences of global supply chain crises. In particular, as Asian ports are among those that have been seriously impacted by the COVID-19 pandemic, the efficiency of Asian ports is of significant importance, which is the focus of this paper.

Containerization has changed how global supply chains in general and shipping in particular function because it has significantly influenced operations through the unitization of break-bulk cargo. Since its introduction in 1956, there has been a significant increase in container

[16] The research of this chapter is obtained in collaboration with Prof. Dr. Nicole Adler, Hebrew University of Jerusalem, Prof. Dr. Georg Hirte, TU Dresden and Prof. Dr. Hans-Martin Niemeier, Hochschule Bremen City University of Applied Sciences. The paper is not yet submitted for publication.

trade because it facilitates the mechanization of cargo handling, improving the performance of seaports and supply chains compared to break-bulk cargo handling. It enables efficient door-to-door delivery because it is easy to transfer containers between different modes of transport such as ships, rail, and trucks without needing extra cargo handling such as the packing and unpacking of cargo contained within the containers. Containerization has been the most dynamic aspect of globalization, far exceeding the growth in the value of exports and GDP (Guerrero and Rodrigue, 2014). Rodrigue and Notteboom (2009) argue that no other technical improvement has contributed more to globalization than containerization. Seaports handling containers realize improved efficiency leading to higher service quality as containers can reduce the turnaround times of vessels compared to break-bulk cargo. Moreover, transport undertakings such as shipping lines, railway firms, and trucking companies benefit from economies of scale due to containerization. Due to these reasons, containerised trade has expanded at the fastest rate compared to other cargoes, with volumes rising at an annual average rate of 8% between 1980 and 2018 (UNCTAD, 2019) and further scope for growth.

Seaports play a vital role in container trade value chains because most containers transit through seaports during their voyage to the final destination. As a result, seaport performance in handling containers significantly impacts the time and cost related to the final delivery of the container. Further, port efficiency is particularly relevant for mature seaports subject to increasing competition with secondary markets (Hayut, 1981), land and capacity constraints (Notteboom and Rodrigue, 2009), and consequences of containerization waves (Guerrero and Rodrigue, 2014). Given these external changes, one can hypothesise that port governance has become increasingly crucial for the port's efficiency, and one of the roles of port authorities is to enhance efficiency (Goss, 1990). The port authority plays a key role in port governance as it is responsible for the administration and management of port infrastructures and the coordination and control of activities of the different actors present at the port (Notteboom and Haralambides, 2020).

This is our point of departure. We study the impact of ownership and regulation as port-governance-related variables and their interaction with hinterland competition on the ports' efficiency. Our study field is Asia because there is a sufficiently large number of container seaports. We do not study all facets of port governance but focus on ownership and regulation as two governance-related variables.

We refer to the World Bank (2007) which defines four governance models that are linked to port ownership: the service, tool, landlord, and private service seaport model. The service and tool port serve public interests, the private service seaport serves the interests of private shareholders, and the landlord seaport balances public and private goals. These models are closely related to ownership. A complete discussion of port governance is out of the scope of the paper. Concerning efficiency, we refer to Vieira et al. (2014), who perform a systematic review of port governance and performance studies.

Port governance has been changing as more private money has been infused into the system resulting in higher competition, higher productivity, and lower costs (Notteboom and Haralambides, 2020). Further, private participation has been increasing among seaports. Due to the broad range of services offered by seaports, we observe that the private sector participates in providing a vast majority of these services. Brooks and Cullinane (2006) survey 42 ports worldwide and find that only four ports operate as fully public ports, and only one port operates as a fully private port. Most of the ports in their sample operate with a public-private partnership agreement.

In the case of container ports, specialised private terminal operators who often operate container terminals worldwide are argued to have higher total factor productivity (Cheon et al., 2010). Moreover, state involvement may be beneficial because ports get support from the state in providing transportation infrastructure, and the government may prefer their seaports, implying a higher cost-efficiency (Zheng and Yin, 2015). Public participation may also be beneficial because of the public stakeholder's knowledge of the upstream and downstream markets (Yuen et al., 2013). Combining these factors could lead to a better performance of container ports with a public-private partnership agreement.

Governance-related factors apart from ownership affecting port performance are competition and economic regulation. Dappe and Suarez-Aleman (2016) find evidence that container ports facing higher inter- and intra-port competition are more efficient. On the other hand, competition can also lead to excessive entry and overcapacity, which can harm efficiency. If there is local monopoly power with no effective competition, private participation generates the need for economic regulation. The most commonly applied price regulation tools to ports are price-cap regulation and rate-of-return regulation. There are also hybrid regulatory systems that contain pricing elements and profit limits (Tovar et al., 2004; Defilippi and Flor, 2008).

On the institutional side, economic regulation may be imposed from various levels of government, the port authority, an independent regulatory institution, or be market-based with no explicit economic regulation (see Ferrari et al. (2022) for case studies on seaport regulation). Zheng and Negenborn (2014) compare the impact of economic regulation from the central government to the impact of having a decentralized market-based pricing regime by applying principal-agent theory and dynamic game theory. They apply their analysis to the Port of Shanghai in China. They find port efficiency, demand, and social welfare are higher with the decentralized market-based pricing regime than with centralized government regulation. They also find that tariffs are lower with the decentralized market-based pricing regime than with centralized government regulation because competition from local government-owned terminal operators leads to lower tariffs in their decentralized market-based pricing model.

Sauri and Robuste (2012) use principal-agent theory and model the concession between a private container terminal operator and the port authority as a moral hazard problem with hidden information. They show that the private container terminal operator can be incentivized to be more productive and reduce tariffs as if the container terminal operator was in a competitive market when the private container terminal operator has to pay an annual fee to the port authority, which is based on the estimation of the container terminal's cost and tariffs in a competitive market. This is evidence that port authority regulation may also be efficiency-enhancing under certain circumstances. Adler et al. (2021) show that regulation by an independent regulator enhances the technical efficiency of Indian major seaports.

In summary, on the institutional side, in the presence of effective competition, market-based pricing leads to an efficient outcome, and regulation by an independent regulator also increases technical efficiency. Regulation by a government ministry may lead to a less than efficient outcome due to the possibility of regulatory capture. Finally, the efficiency implications of economic regulation by the port authority are unclear. It may be efficiency-enhancing, but the port authority may also be susceptible to regulatory capture provided that it is also involved in port operations or earns rent which is a function of the terminal operator's revenues or profits.

This brief review shows that container ports' efficiency plays a significant role in global supply chains. As there has been a trend of devolution in port governance, it becomes useful to analyse the impact of port governance from an efficiency perspective. Introducing private participation has also shifted the intensity of hinterland and transshipment competition among container ports. The absence of effective competition may necessitate the imposition of economic regulation to prevent the container ports from abusing their market power. As the various regulatory institutions described above have different motives and incentives, it is also of relevance to empirically test the effectiveness of the regulatory institutions in promoting container port efficiency. As a result, this paper aims to assess the impact of governance-related factors such as ownership, competition, and institutional regulation on the technical efficiency of container ports. We test the individual and combined effects of the governance-related factors on the efficiency of container ports to analyse and compare various governance-related settings prevalent among container ports.

In order to examine the impact of governance-related factors such as ownership, competition, and economic regulation on the technical efficiency of container ports, we estimate production frontiers for an unbalanced panel dataset of 43 container ports from the Far East and Asian region between 1986 and 2010.

We are not the first who study the efficiency of seaports. Yan et al. (2009) analyse the technical efficiency of 141 container terminal operators in 78 container ports from the world's top 100 container ports between 1997 and 2004 and find that a country's trade volume positively impacts output with the strongest effect in East and South Asia. Moreover, Medda and Liu (2013) examine the technical efficiency of 165 container terminals worldwide in 2006, finding that Far East Asia's container terminals are more technically efficient than the other terminals in the rest of the world. However, to the best of our knowledge, we are the first to empirically study the sources of technical efficiency of container ports in the Far East and Asian region. Our contribution to the literature is threefold. Firstly, we empirically estimate the impact on technical efficiency of vital governance-related factors such as ownership, competition and economic regulation. Secondly, we estimate the impact on technical efficiency of both hinterland competition and transshipment competition. Thirdly, we estimate the individual and combined effects of the governance-related contextual variables on technical efficiency of container ports in the Far East and Asian region.

The rest of the paper is structured as follows: Section 4.2 provides a survey of the literature, Section 4.3 the SFA models and data used, and Section 4.4 displays the results of the individual and combined effects SFA models. Eventually, Section 4.5 concludes and provides directions for future research.

4.2. Literature Survey

Two methodologies, namely, data envelopment analysis (DEA) and stochastic frontier analysis (SFA), have been extensively applied to study the efficiency and performance of seaports. As this paper employs SFA to analyse the technical efficiency of container ports in the Far East and Asian region, we review only the papers that have applied SFA to the efficiency of seaports. More specifically, we review SFA papers that focus on the impact of governance models and reform programs, and analyse the impact of ownership, competition, and regulation, or of both hinterland and transshipment competition on the performance of the seaports. Table 4.1 gives an overview of the literature survey of SFA papers that focus on the governance of seaports. The reader is referred to Gonzalez and Trujillo (2009) for a survey of DEA and SFA studies and to Panayides et al. (2009) for a literature survey of DEA studies on the performance analysis of seaports. Odeck and Brathen (2012) provide a meta-analysis of DEA and SFA studies on the technical efficiency of seaports.

With regards to governance and reform, a series of papers document the governance model and the reform process of Spanish seaports and the impact of the reform process on the efficiency of the Spanish seaports. The first reform program in Spain began in 1992 with the primary objectives of decentralization and the promotion of autonomy of the port authorities. This reform program changed ports from service and tool ports to landlord ports, created port authorities, promoted inter-port competition, and created the state-owned enterprise of national ports. The second reform took place in 1997 with the objectives of promoting autonomy, encouraging higher participation and its regulation of the regional government in port management, and encouraging private sector participation. The reform program of 2003 encouraged higher private sector investment and promoted inter- and intra-port competition. It also significantly reduced some of the port authorities' responsibilities (Gonzalez and Trujillo, 2008; Nunez-Sanchez and Coto-Millan, 2012; Rodriguez-Alvarez and Tovar, 2012; Coto-Millan et al., 2016).

Gonzalez and Trujillo (2008) analyse the technical efficiency of nine major Spanish port authorities from 1990 to 2002. Their results show that the first reform led to a technological change of 6.3%, and the second led to a technological change of 3.8%. While their results show a modest change in technical efficiency, the authors argue that the reforms seem to have stimulated a catching up of the poor performers. Nunez-Sanchez and Coto-Millan (2012) analyse the total factor productivity of 27 Spanish port authorities from 1986 to 2005. They find an average technical efficiency of the port authorities of 78.6% and a TFP growth rate of 2.82% over the time period. The authors conclude that the reform programs of 1992, 1997, and 2003 were responsible for an increase in total factor productivity.

Coto-Millan et al. (2016) estimate the technical efficiency of 26 Spanish port authorities for a 27 year time period ranging from 1986 to 2012. They find that the reform programmes implemented in 1997 and 2003 had a significant positive impact on the technical efficiency of the Spanish port authorities. As a result, the authors conclude that autonomy, private sector participation through public-private partnerships, and competition promote the technical efficiency of ports. Rodriguez-Alvarez and Tovar (2012) analyse the impact of port reforms on the cost efficiency of 26 Spanish port authorities from 1993 to 2007. They find that the reform programs of 1992 and 1997 positively impact cost efficiency. Contrary to the results obtained by Nunez-Sanchez and Coto-Millan (2012) and Coto-Millan et al. (2016), Rodriguez-Alvarez and Tovar (2012) find that the reform program of 2003 harmed cost efficiency. The authors argue that the third reform program reduced cost efficiency mainly due to the delay in implementing some of the measures outlined in the reform program.

Concerning the promotion of more autonomy, Coto-Millan et al. (2000) analyse the economic efficiency of 27 Spanish ports between 1985 and 1989 and find that greater autonomy leads to a higher economic inefficiency in the pre-reform period. In contrast, Nunez-Sanchez and Coto-

Millan (2012) find that post-reform autonomous ports have higher total factor productivity growth rates compared to port assemblies. This confirms that after implementing the reforms, autonomous Spanish ports have performed better than non-autonomous Spanish ports. This is not the case only in Spain. For example, Bergantino and Musso (2011) analyse the technical efficiency of 18 southern European seaports from 1995 to 2007. They found that seaport autonomy positively affects the reduction of the input slack.

Seaport reform and efficiency have also been analysed in Africa, Chile, Mexico, Peru, and Vietnam. Estache et al. (2002) estimate the technical efficiency of 11 Mexican ports from 1996 to 1999. They focus on port reform in Mexico, which started in 1993. The main objectives of the reform were to establish a legal framework for private firms to participate in the terminal operation in the Mexican port sector. The key instruments of the reform were decentralization, privatization, and the introduction of competition. As the Mexican ports are price-capped, they build a production frontier to estimate efficiency gains that could be used for the downward revision of price caps. They also argue that benchmarking with the measurement of productive efficiency can be used for yardstick competition that incentivizes the poorest performers to improve their efficiency. Their results show that the reform has had a significant positive impact on the performance of the 11 Mexican ports, and they find that the average annual efficiency gain in the sector is between 2.8-3.3%. This is the amount by which the maximum tariffs could be reduced when reviewing the price caps.

Trujillo et al. (2013) analyse the technical efficiency of 37 African container ports between 1998 and 2007. They find that the average technical efficiency for the African container ports is 30%. Even though the average technical efficiency level is very low, because annual average port efficiency has improved over time, the authors argue that port reforms enhance technical efficiency.

Chang and Tovar (2014a) analyse the reform process of Chilean and Peruvian ports and compare the performance of 14 Peruvian and Chilean terminals from 2004 to 2010 by applying stochastic frontier analysis. Despite a decline in the total factor productivity of Chilean terminals due to the global financial crisis of 2008 and an improvement in the total factor productivity of Peruvian terminals, the authors find that the Chilean terminals performed better than the Peruvian terminals on average. The authors argue that the higher efficiency of the Chilean terminals is due to the port reform process in Chile, which has been more dynamic than the reform process in Peru. This attracted a higher private sector participation in Chilean port terminals leading to higher investment in infrastructure and technology.

Nguyen et al. (2018) analyse the technical efficiency of the 43 largest Vietnamese ports in 2015. They argue that port restructuring and reform in the form of corporatization and commercialization can improve the technical efficiency of the ports under consideration. They further argue that port development strategies should vary by region and find that the ports in the north are the most technically efficient.

Reference	Region	Timeframe	Ownership	Hinterland Competition	Transshipment Competition	Regulation	Effects Explicitly Analysed
Bergantino and Musso (2011)	Southern Europe	1995-2007	No	No	No	Yes	Yes
Chang and Tovar (2014a)	Chile and Peru	2004-2010	Yes	No	No	No	No
Chang and Tovar (2014b)	Chile and Peru	2004-2010	Yes	No	No	No	Yes
Coto-Millan et al. (2000)	Spain	1985-1989	No	No	No	No	No
Coto-Millan et al. (2016)	Spain	1986-2012	Yes	Yes	No	Yes	Yes
Cullinane and Song (2003)	South Korea and United Kingdom	1978-1996	Yes	Yes	No	Yes	No
Cullinane et al. (2002)	Asia	1989-1998	Yes	No	No	Yes	No
Cullinane et al. (2006)	Worldwide	2001	Yes	No	Yes	No	No
Estache et al. (2002)	Mexico	1996-1999	Yes	Yes	No	Yes	No
Gonzalez and Trujillo (2008)	Spain	1990-2002	Yes	Yes	No	Yes	No
Liu (1995)	United Kingdom	1983-1990	Yes	No	No	No	Yes
Lopez-Bermudez et al. (2019a)	Brazil	2008-2017	Yes	Yes	No	No	Yes
Lopez-Bermudez et al. (2019b)	Argentina	2012-2017	Yes	No	No	No	Yes
Merkel (2018)	Europe	2002-2012	No	Yes	No	No	Yes
Nguyen et al. (2018)	Vietnam	2015	No	No	No	No	No
Notteboom et al. (2000)	Europe and Asia	1994	Yes	Yes	Yes	No	No
Nunez-Sanchez and Coto-Millan (2012)	Spain	1986-2005	Yes	Yes	No	Yes	No
Perez et al. (2016)	Latin America and the Caribbean	2000-2010	No	Yes	Yes	No	Yes

Reference	Region	Timeframe	Ownership	Hinterland Competition	Transshipment Competition	Regulation	Effects Explicitly Analysed
Rodriguez-Alvarez and Tovar (2012)	Spain	1993-2007	Yes	Yes	No	Yes	No
Rodriguez-Alvarez et al. (2007)	Spain	1991-1999	No	No	No	Yes	No
Sarriera et al. (2013)	Latin America and the Caribbean	1999-2009	Yes	No	Yes	No	Yes
Serebrisky et al. (2016)	Latin America and the Caribbean	1999-2009	Yes	No	Yes	No	Yes
Suarez-Aleman et al. (2016)	Developing Countries	2000-2010	Yes	No	Yes	No	Yes
Tongzon and Heng (2005)	Asia, Europe and North America	1999	Yes	Yes	No	Yes	Yes
Trujillo et al. (2013)	Africa	1998-2007	Yes	No	No	No	Yes
Wang et al. (2013)	United States	1997-2006	Yes	No	No	No	Yes
Wanke et al. (2011)	Brazil	2008	Yes	No	No	No	Yes
Zheng and Yin (2015)	China	1998-2011	Yes	No	No	No	No

Table 4.1: Overview of SFA studies on governance of seaports

Regarding ownership, most papers assess the impact of private participation and the impact of the landlord seaport model on the efficiency of the seaports. In this model, the port authority is the landlord, a public institution. The terminal operators are private entities responsible for the operation and management of the terminals, the operating rights of which are granted via concession contracts. As full privatization is not very common among seaports, the impact of full privatization on the efficiency of seaports is an under-researched topic. Cullinane et al. (2006) analyse the technical efficiency of 57 container ports or terminals located within the 30 top container ports in the world in 2001. Their results show that higher private sector participation leads to a higher technical and scale efficiency.

Chang and Tovar (2014b) analyse the technical efficiency of 14 Chilean and Peruvian port terminals from 2004 to 2010. They find that even though the global financial crisis affected the efficiency of the port terminals in both countries, the Chilean port terminals have a higher time-varying technical efficiency level than the Peruvian port terminals. Regarding management type, the authors find that privately operated terminals are more technically efficient than publicly operated terminals. The authors argue that this is because privatization minimizes bureaucracy, which promotes investment and allows for greater flexibility in hiring employees.

Wanke et al. (2011) analyse the technical efficiency of 25 Brazilian port terminals in 2008. In their analysis, private terminals are more efficient than public terminals. Lopez-Bermudez et al. (2019a) study the technical efficiency of 20 Brazilian container terminals from 2008 to 2017. As the modified port legislation introduced in 2013 encourages private participation, the authors find that private terminal operators such as Tecon, Libra, and APM Terminals are more technically efficient than their public counterparts. Lopez-Bermudez et al. (2019b) study the technical efficiency of 13 container terminals in Argentina from 2012 to 2017. They find that private terminal operators are more efficient than public terminal operators and suggest that collaboration between the public and private sectors can improve the technical efficiency of Argentine container terminals.

There are some studies on the performance impact of the landlord seaport model. Sarriera et al. (2013) estimate the technical efficiency of 63 container ports from Latin America and the Caribbean between 1999 and 2009. The authors find that landlord ports are more efficient in comparison to the other ports, although the results are not statistically significant. Trujillo et al. (2013) find landlord ports are the most efficient in Africa. The authors further analyse service quality. They provide evidence that landlord seaports have the highest service quality compared to African tool and service ports. Serebrisky et al. (2016) analyse the technical efficiency of 63 container ports from Latin America and the Caribbean from 1999 to 2009. They find that private sector participation and the landlord seaport model result in higher technical efficiency. Suarez-Aleman et al. (2016) analyse the technical efficiency of 203 container ports from 70 developing countries between 2000 and 2010. The authors find that landlord ports are significantly more technically efficient than ports not operating under the landlord port model. Finally, Wang et al. (2013) analyse the profit efficiency of 46 US ports from 1997 to 2006. After controlling for output price, capital intensity, labour cost, and size, they find landlord ports in the US are more profitable than limited-operating and operating ports.

Regarding full privatization, Liu (1995) compares the technical efficiency of 28 trust, municipal and private British ports between 1983 and 1990. He finds that there is no significant difference in efficiency between trust, municipal and private ports and concludes that ownership has little to no impact on the technical efficiency of the British ports. On the other hand, he finds that port location and size significantly impact technical efficiency, with east coast ports being more technically efficient than west coast ports and a larger port size having a significant positive impact on technical efficiency. Notteboom et al. (2000) analyse the technical efficiency of 36 European container terminals and four Asian container terminals in 1994, and they also find that ownership structure has no significant impact on technical efficiency levels.

Contrary to the ownership results obtained above, Tongzon and Heng (2005) analyse the technical efficiency of 25 container ports/terminals from Asia, Europe, and North America in 1999. They find that private sector participation positively impacts technical efficiency. However, full privatization does not lead to higher technical efficiency. On the contrary, they find that privatization at the level of around 80% is the most conducive to container port technical efficiency. They argue that the terminal operators should be landowners and operators while the port authorities should take up the role of the regulator in order for the container port/terminal to exhibit high technical efficiency. Similar results are obtained in the case of China. Zheng and Yin (2015) analyse the technical, cost, and allocative efficiency of 16 Chinese ports from 1998 to 2011. They find that more than 50% state-owned ports have a higher cost-efficiency. They argue that these ports get support from the state in providing transportation infrastructure and preferential policies from the government, which leads to higher cost-efficiency. Based on the literature regarding the performance impact of ownership, we formulate the following hypothesis:

Hypothesis 1 (performance impact of private participation and the landlord seaport model): Private participation and the landlord seaport model have a positive impact on technical efficiency.

While ownership affects port governance, competition may also drive port efficiency. According to Vickers and Yarrow (1988), market competition and the regulatory environment are more important than the ownership of firms. Dappe and Suarez-Aleman (2016) find that the total time ships spend at the port is shorter when the operating environment is more competitive. They argue that this is because container ports in a competitive environment must perform better to attract and retain traffic.

Following Verhoeff (1981), ports compete in geographical hierarchies. He emphasises three hierarchies. The first is where port ranges compete with each other. The second is where port areas and ports in a certain range compete with each other. The last is the competition of ports in a particular port area. While the second and the third hierarchies result in hinterland competition, the first hierarchy could result in transshipment competition. He notes that due to the economic importance of ports, public authorities often subsidize ports which puts them in an advantageous position by being able to set lower prices. He argues that competition has to take place based on real costs. As a result, port pricing should be based on cost recovery where price equals long-run marginal costs, which is an efficient outcome (Haralambides, 2002).

Competition can also lead to excessive entry and overcapacity, which can harm efficiency. Wang et al. (2012) argue that port cooperation could be a remedy. Although, from their game-theoretic model, cooperation is unlikely unless the container ports with the lower net absolute advantage become cost-efficient and differentiate their services. Homsombat et al. (2016)

provide similar results by showing that a more competitive port will be in a better position to cooperate with other stakeholders. For transshipment competition, Anderson et al. (2008) argue that there is an excessive investment in transshipment capacity in East Asia that may drive prices down to such an extent that the container ports making these investments may not recover their investment costs. Moreover, the ports could lose market shares (Ishii et al., 2013).

For hinterland competition, Merkel (2018) analyses the technical efficiency of 77 large European container ports between 2002 and 2012. He finds that an increase in inter-port competition within a proximity of 300 kilometres leads to an increase in the technical efficiency of the container ports. More specifically, he finds that a one percentage point decrease in market concentration leads to a 1.2 percentage point increase in technical efficiency, and he proposes pro-competitive port policy and regulation in the European Union. Perez et al. (2016) study the technical efficiency of 40 container ports in 19 countries from Latin America and the Caribbean from 2000 to 2010 while also analysing the effects of intra-port competition on efficiency. The authors find that ports with three or four container terminals are more technically efficient than ports with one or two container terminals. The authors suggest that future policies should promote intra-port competition.

Contrary to the results obtained by Merkel (2018) and Perez et al. (2016), Lopez-Bermudez et al. (2019a) find that the technical efficiency of the Brazilian terminals has dropped from 66% in 2008 to 51% in 2017. They cite competitive effects as the main reason for this drop in efficiency. Moreover, Notteboom et al. (2000) find that the maximum efficiency level obtained in their analysis is 85%, and the authors argue that the analysed European and Asian container terminals have overcapacity to address competition. On the other hand, they also find that small terminals located at larger container ports achieve higher technical efficiency levels due to the cargo generating effect of the port, availability of port operating know-how, and higher intra-port competition. Our hypothesis regarding the performance impact of hinterland competition is as follows:

Hypothesis 2 (performance impact of hinterland competition): Container ports facing high hinterland competition are more technically efficient than those facing low hinterland competition.

Regarding transshipment competition, Cullinane et al. (2006) show that transshipment ports are more technically efficient than gateway ports. They argue that this is because transshipment ports are more competitive and focus more on technical efficiency due to the footloose nature of transshipment traffic. Notteboom et al. (2000) also find that hub port terminals achieve a higher level of technical efficiency than feeder port container terminals. Sarriera et al. (2013) find that transshipment ports in Latin America and the Caribbean are more technically efficient than ports that do not handle transshipment traffic. Suarez-Aleman et al. (2016) find that transshipment ports in developing countries have a significantly higher output than ports that are not transshipment hubs. In contrast, Perez et al. (2016) find that transshipment ports are less technically efficient than non-transshipment ports. We hypothesize that the impact of transshipment competition will be as follows:

Hypothesis 3 (performance impact of transshipment competition): Transshipment competition has a positive impact on the technical efficiency of container ports.

A few studies focus on factors affecting port competitiveness. For example, Tongzon and Heng (2005) argue that technical efficiency, port selection preferences of carriers and shippers, and landside accessibility have the strongest influence on port competitiveness. Further analysis reveals that the adaptability of the port to customers' demands also significantly impacts its competitiveness.

Private participation with local monopoly power generates the need for economic regulation. This is especially the case when ports face no effective competition (Dappe and Suarez-Aleman, 2016; Defilippi, 2004). This occurs at some ports with captive traffic (Tovar et al., 2004). Economic regulation of ports is either access or price regulation. Access regulation sets the conditions under which competing firms may use the facilities controlled by the monopolist, with the efficient prices being set by market forces. Using the essential facilities doctrine, the regulator attempts to ensure that the monopolist grants access to its facilities to competitors under reasonable conditions (Defilippi and Flor, 2008).

Price-cap regulation, rate-of-return regulation, and hybrid regulatory systems are used for the price regulation of seaports (Tovar et al., 2004; Defilippi and Flor, 2008). The advantage of price-cap regulation is that it gives the container terminal operator an incentive to be efficient, with the disadvantage that service quality could be compromised and environmental damage increased due to the cost reduction strategy of the terminal operator (Tovar et al., 2004). Moreover, price-cap regulation may also lead to the ratchet effect, which is the lack of incentives to be productively efficient when the period between price reviews is too short. While a global price-cap can lead to Ramsey prices, it may result in predatory pricing when some of the markets supplied by the monopolist are contestable (Defilippi and Flor, 2008). Rate-of-return regulation diminishes capital risks as profits are guaranteed. However, it does not provide the terminal operator with an incentive to be efficient, can lead to the Averch-Johnson effect, and may also lead to regulatory capture due to the high degree of discretion needed by the regulator in order to implement this form of regulation (Tovar et al., 2004; Defilippi and Flor, 2008).

Hybrid regulatory systems aim to combine the advantages of both systems while preserving product and environmental quality. Economic regulation may be unnecessary when competition is feasible. Even with no competition, heavy-handed regulation may be unnecessary when there is potential competition. In this case, the regulator's role would be to impose a periodical control on prices to prevent collusion among competitors (Tovar et al., 2004).

For regulation, Cullinane et al. (2002) analyse the technical efficiency of 15 Asian container ports or terminals from 1989 to 1998. They find that privatization and deregulation positively impact the technical efficiency of the ports or terminals. Moreover, Cullinane and Song (2003) analyse the technical efficiency of two Korean and three British container terminals from 1978 to 1996. They find that a higher degree of privatization and deregulation leads to higher technical efficiency. They suggest that higher privatization with the promotion of higher competition will lead to a higher technical efficiency among container terminals. Rodriguez-Alvarez et al. (2007) study the technical and allocative efficiency of three port terminals located in the Las Palmas port in Spain from 1991 to 1999. They find that labour-related regulations negatively affect allocative efficiency limiting the terminal operators' flexibility. Our hypothesis with regard to the performance impact of regulation is as follows:

Hypothesis 4 (performance impact of economic regulation): Deregulation positively impacts the technical efficiency of container ports.

Table 4.1 shows that SFA has been applied to measure the efficiency and the impact of governance-related factors on the performance of seaports worldwide. One typical result is that private participation and the landlord seaport model improve the performance of seaports in most of the applied literature regardless of the region. However, only a few studies explore the impact of hinterland and transshipment competition and economic regulation. Therefore, these factors need to be further analysed to understand the impact of governance-related factors on the efficiency of seaports. From Table 4.1, it becomes evident that some studies do not explicitly model the impact of the contextual variables on seaport efficiency. Hence, the explanatory power of their models regarding the impact of governance on seaport efficiency is limited. Moreover, it also becomes evident from Table 4.1 that most studies do not control for the factors related to governance when measuring the impact of the contextual variables on seaport efficiency. Only two studies, namely Coto-Millan et al. (2016) and Tongzon and Heng (2005), have explicitly analysed the impact of ownership, competition, and regulation on the efficiency of seaports. However, both studies do not differentiate between hinterland and transshipment competition. Coto-Millan et al. (2016) focus on the Spanish reform programs and use dummies to indirectly measure the impact of governance on the ports' efficiency. Tongzon and Heng (2005) measure the impact of private participation and regulation in their first stage efficiency analysis and perform a second stage principal components analysis to measure the impact of factors affecting port competitiveness.

Our study contributes to the literature by measuring the direct impact of governance, both hinterland and transshipment competition, and institutional regulation on the technical efficiency of seaports. We also study the impact of private participation and the landlord seaport model on seaports' technical efficiency. Finally, we measure both the individual and the combined effects of the governance-related contextual variables on the technical efficiency of seaports in the Far East and Asian region. Our hypothesis regarding the combined effects of the governance-related contextual variables on the technical efficiency of container ports is as follows:

Hypothesis 5 (combined performance impact of ownership, hinterland competition and economic regulation): A majority private container port that faces high hinterland competition and has no economic regulation is the most technically efficient.

4.3. SFA Models and Data

We apply SFA to measure the technical efficiency of container ports in the Far East and Asian region. The reason to choose SFA is that it incorporates statistical noise and can be used to conduct hypotheses tests (Coelli et al., 2005, p. 312). Moreover, as we can estimate a production frontier with SFA, we have chosen this methodology due to many of its desirable properties.

In an SFA production frontier model, the output is composed of three components. The first term represents the production function. The second term is an asymmetrically distributed random effect term which accounts for inefficiency. The third term is a random error component which accounts for the total impact of all types of errors. A technical efficiency value of one implies full efficiency and a value below one indicates the level by which the output can be increased in order for the firm to become efficient. Aigner et al. (1977) and Meeusen and van den Broeck (1977) formulated the concepts underlying SFA, wherein the production process consists of producer-level random variations. The assumptions that are made in an SFA model are that technical efficiency is less than or equal to one; the random effect term is greater than or equal to zero; the random effect term is independent of the random error component; the random effect term and the random error component are independent of the inputs; and the random effect term and the random error component are *iid* across the producers. While initial contributions used the Cobb-Douglas (1928) production function to model the production process, more recent contributions have used the more flexible translog production function due to many of its desirable properties.

In this paper, we apply the panel data SFA model proposed in Battese and Coelli (1995). They formulate a stochastic production frontier for unbalanced panel data where technical inefficiency is assumed to be a function of producer-specific contextual variables and time. The inefficiency effects are assumed to have a truncated normal distribution with constant variance and with means which are a linear function of the contextual variables. In this model, the parameters of the stochastic frontier and those of the inefficiency model, which include the coefficients of the contextual variables, are estimated simultaneously along with the technical change and the time-varying technical efficiencies. More specifically, for N firms over T time periods, the authors define output Y_{it} and the random effect term U_{it} as follows:

$$Y_{it} = f(x_{it};\beta)\exp(V_{it} - U_{it})$$

and

$$U_{it} = z_{it}\delta + W_{it}$$

where Y_{it} is the output of firm i in period t; $f(x_{it};\beta)$ is a production function with inputs x_{it}, associated with firm i in period t; β is the parameter vector which has to be estimated; V_{it}'s are iid $N(0,\sigma_v^2)$ random errors; the U_{it}s are non-negative random variables independently distributed with a truncated normal distribution with mean $z_{it}\delta$ and variance σ^2; z_{it} is a vector of contextual variables associated with technical inefficiency; δ is a vector of the coefficients of the contextual variables which has to be estimated; and W_{it} has a truncated normal distribution with zero mean and variance σ^2 such that $W_{it} \geq -z_{it}\delta$. As a result, U_{it} has a non-negative truncated $N(z_{it}\delta, \sigma^2)$ distribution and the technical efficiency of firm i in period t can be obtained by $TE_{it} = \exp(-z_{it}\delta - W_{it})$. The simultaneous estimation of the parameters is achieved using maximum likelihood estimation.

We apply the model proposed by Battese and Coelli (1995) to an unbalanced panel dataset of 43 Asian container ports observed between 1986 and 2010. The data is sourced from the Containerisation International Yearbooks (1988-2012). We have data on container ports from 12 Asian countries, which spans over 25 years. The container ports are from China, India, Indonesia, Japan, Malaysia, Pakistan, Philippines, South Korea, Sri Lanka, Taiwan, Thailand and Vietnam. The dataset contains 591 observations and Figure 4.1 contains a map of the ports in the dataset.

We apply two SFA models in the paper in order to make inferences of the impact of governance on the technical efficiency of the container ports in the dataset. The SFA models are as follows:

Model 1

$$lny_{it} = TL(lnx_{k,it}, t; \beta) + v_{it} - u_{it}$$

$$u_{it} = |N(m_{it}, \sigma_u^2)| \ where \ m_{it} = \delta_0 + \sum_j^M \delta_j z1_{j,it}$$

Model 2

$$lny_{it} = TL(lnx_{k,it}, t; \beta) + v_{it} - u_{it}$$

$$u_{it} = |N(m_{it}, \sigma_u^2)| \ where \ m_{it} = \delta_0 + \sum_j^M \delta_j z2_{j,it}$$

In the first model we add contextual variables ownership type, hinterland and transshipment competition and the regulation type to study Hypotheses 1-4. This model is a translog production function with technical change which is extended by individual effects of the contextual variables that explain technical inefficiency. Since our main focus is on the interaction of the contextual variables we add the combined effects of the contextual variables as determinants of technical inefficiency. This gives us the second model which is our main model which is also a translog production function with technical change. We apply two additional models as robustness checks. The first additional model is a translog production function with technical change and the second additional model is a translog production function with technical change where the individual effects of the contextual variables explain output. These models apply the Battese and Coelli (1992) formulation and the results of these additional models are provided in Appendix 4.A.

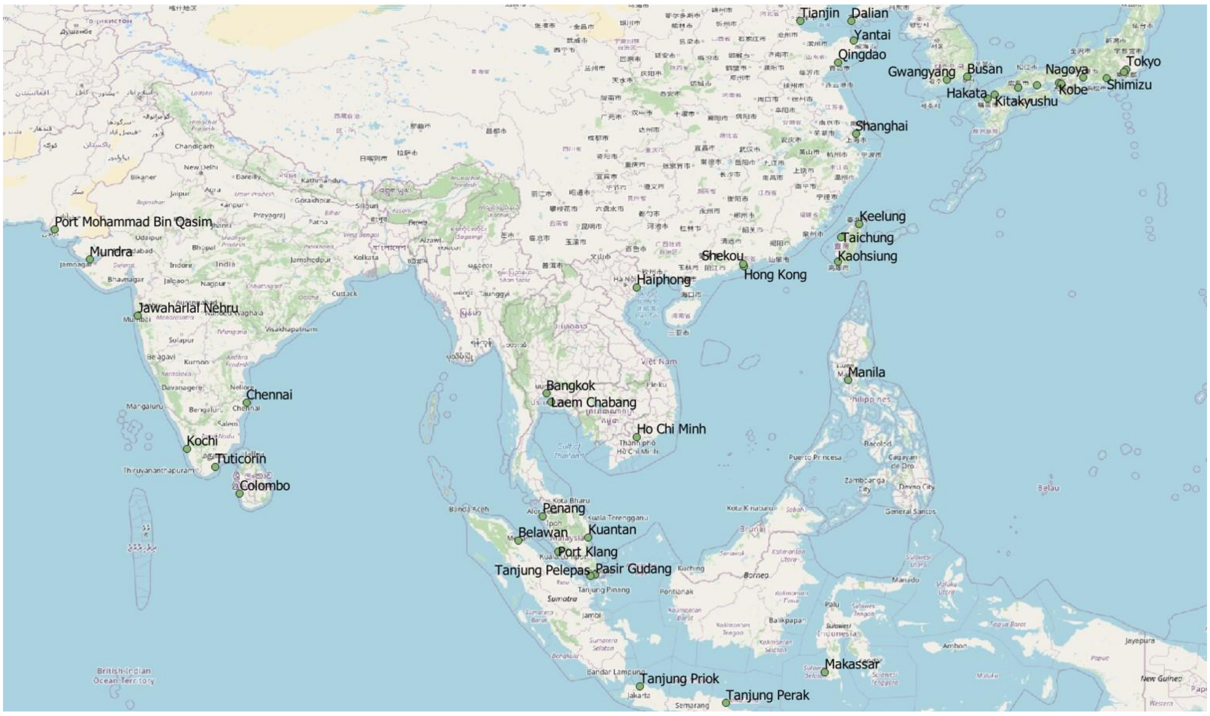


Figure 4.1: Map of ports in the dataset

The Containerisation International Yearbooks sometimes report data at the level of the terminal and sometimes report data at the level of the berth. As there is no consistent data at the terminal level, we cannot perform a terminal level analysis and the data has been aggregated to the level of the container port to perform the analysis. The output y_{it} is the total number of Twenty-Foot Equivalent Units (TEU) handled by a container port i in year t, which is the output that has most often been included in analyses of container port technical efficiency. We follow Trujillo et al. (2013) and include three inputs in the analysis. The first input is the total berth length at the level of the container port. This is a proxy for capital. The second input included is the total terminal area aggregated at the level of the container port. This serves as an indicator of the land available at the container ports. The third input included is the total number of cranes. Even though this is a capital input, this also serves as a proxy for the amount of labour utilized by the container ports and also as a proxy for the amount of variable inputs such as energy used by the container ports. As a result, the number of cranes, being a capital input, is used as a proxy for labour and energy as we do not have data on these variables. Previous research papers have argued that the number of cranes is a good proxy for labour and energy because this input is used in fixed proportions to labour and energy, and accounting for this factor is equivalent to accounting for the other two missing factors (Cullinane and Song, 2006; Cullinane et al., 2006; Merkel, 2018; Notteboom et al., 2000; Tongzon and Heng, 2005; Sarriera et al., 2013; Serebrisky et al., 2016; Trujillo et al., 2013).

Table 4.2 contains the descriptive statistics of the inputs and the output included in the SFA models. An average port in the dataset handles around 2.5 million containers and has a berth length of around 3.1 kilometres, a terminal area of around 1 million square metres, and around 68 cranes. As can be seen from the descriptive statistics, there is a large dispersion in the data apparent from the standard deviation figures. There are significantly small ports in the dataset, with the smallest port handling just over 100,000 containers, and there are very large ports in the dataset, with the largest port handling over 29 million containers annually. As a result, the dataset is a good representation of the container ports present in Asia, and the estimated production frontiers will be a good representation of the production process of container ports in Asia. Table 4.3 contains the correlation matrix of the inputs and the output. It shows that the number of cranes is closely correlated to the TEU handled, and we can expect to have a higher value for the elasticity of the number of cranes in comparison to the other inputs. Regarding the within-input correlations, we observe a high correlation between the number of cranes and the terminal area. Nevertheless, as the value is below 0.9, we can justify the use of both inputs in the estimation of the production frontiers, since the correlation is not so high as to exclude the inclusion of either of the inputs in the estimation of the production frontiers.

Variable	Shorthand	Unit	Mean	Median	Std. Dev.	Min.	Max.
TEU Handled	TH	Count	2,565,581	1,348,383	4,180,936	100,700	29,069,000
Berth Length	BL	m	3,172	2,370	2,724	350	14,610
Terminal Area	TA	m^2	1,050,836	740,000	1,137,798	90,000	8,569,837
Number of Cranes	NC	Count	67.93	44	83.46	5	497

Table 4.2: Descriptive statistics of the output and the inputs

Variable	TH	BL	TA	NC
TH	1	-	-	-
BL	0.65	1	-	-
TA	0.81	0.79	1	-
NC	0.95	0.75	0.84	1

Table 4.3: Correlation matrix of the output and the inputs

We focus next on the contextual variables included in the analysis. We include ownership, competition, and regulation as contextual variables in the analysis. For the analysis of the individual effect, we include these variables separately as denoted by $z1_{j,it}$ in Model 1 and evaluate the individual impact of these variables on the technical efficiency of the container ports. For ownership, we focus on the extent of private participation. This is evaluated as the number of private operators out of the total number of operators. It is a ratio between zero and one, with zero indicating no private participation and one indicating that all terminal operators are private firms. One in some instances indicates that the entire container port has been privatized. Moreover, in the case of public-private participation in terminal operation, we have obtained the share of private participation. Table 4.4 contains the descriptive statistics for this variable. We can see that the mean value for private participation is 51%, indicating a significant amount of private participation at the Asian container ports, which has gradually increased over the time duration considered. It should also be noted that there are fully public and fully private container ports in the dataset, as seen from the minimum and maximum values in Table 4.4. For the analysis, we classify container ports as majority private and minority private. A majority private container port has more than 50% private operators out of the total number of terminal operators and a minority private container port has less than 50% private operators out of the total number of terminal operators.

Variable	Mean	Std. Dev.	Min.	Max.
Percentage Private Operators	0.51	0.42	0	1
Percentage Public Operators	0.49	0.42	0	1

Table 4.4: Descriptive statistics of the ownership structure

We evaluate the impact of inter-port competition on the technical efficiency of the container ports in the dataset. We classify inter-port competition as hinterland competition and transshipment competition. For the evaluation of hinterland and transshipment competition, we have included all container ports in Asia. The data is available in the Containerisation International Yearbooks, which comes to a total of 145 container ports.

Hinterland competition occurs when container ports compete for traffic in the same hinterland, and transshipment competition occurs between ports that compete for transshipment traffic. Hinterland competition is measured as the number of ports competing for hinterland traffic within a radius of 1,000 kilometres. We choose a radius of 1,000 kilometres as has been done in Oliveira and Cariou (2015). We assume that ports on separate islands do not compete for hinterland traffic. Hinterland competition is defined as (i) low if there are less than or equal to ten container ports within a radius of 1,000 kilometres, it is (ii) moderate if there are 11 to 20 container ports within a radius of 1,000 kilometres and it is (iii) high when the number of container ports within a radius of 1,000 kilometres is above 20. As can be seen from Table 4.5, most of the ports face low hinterland competition, which comes to a total of 35 container ports. 21 ports in the dataset face moderate hinterland competition, and only 11 ports in the dataset face high hinterland competition.

In order to test the sensitivity of hinterland competition on output and technical efficiency, we perform sensitivity analyses by varying the hinterland competition levels and catchment area. Appendix 4.B presents the results for the varying competition levels. For this sensitivity analysis, hinterland competition is defined as low if there are between zero to five container ports within a radius of 1,000 kilometres. Hinterland competition is defined as moderate if there are between six to ten container ports within a radius of 1,000 kilometres, and hinterland competition is defined as high if there are more than ten container ports within a radius of 1,000 kilometres. Appendix 4.C presents the results when the catchment area has been reduced to 500 kilometres. In this case, hinterland competition is defined as low if there are between zero to five container ports within a radius of 500 kilometres. Hinterland competition is defined as moderate if there are between six to ten container ports within a radius of 500 kilometres, and hinterland competition is defined as high if there are more than ten container ports within a radius of 500 kilometres.

As we do not have data on transshipment traffic, we make estimations of transshipment competition with some justifiable assumptions. Transshipment competition is assumed to occur between the container ports that can handle Post Panamax II vessels. These were the largest types of container vessels until 2010 with a maximum capacity of 8,500 TEU. Container ports with a berth length of at least 340 metres and a draft of at least 15 metres are assumed to be transshipment ports. We further assume that all transshipment ports in the region compete with all other transshipment ports in the region for transshipment traffic. As can be seen from Table 4.5, 16 ports in the dataset are estimated to face transshipment competition. Although, it should be noted that from our estimations, no container port in the dataset faces any transshipment competition before 1995.

With respect to regulation, most regulated container ports in Asia face rate-of-return regulation. The focus here is to analyse the institutional aspect of regulation and to estimate the impact of economic regulation by different institutions on the technical efficiency of the container ports in the dataset. Based on this classification, we have identified three types of institutions that are responsible for regulating container ports in Asia. As a result, we get four levels as there are container ports in Asia that are subject to no regulation. These ports either practice market-based pricing which depends on market conditions or negotiate with the shipping lines on port charges and offer service quality levels. As per our classification, apart from market-based pricing, container ports can be regulated either by the ministry of transport/shipping of the respective country, the port authority, or a separate regulatory institution. As can be seen from Table 4.5, 10 ports in the sample are regulated by the ministry of transport/shipping of the country; 11 ports are regulated by the respective port authority; a minority of six ports is regulated by a separate regulatory institution; and a majority of 18 ports has no explicit economic regulation and follows market-based pricing principles or negotiates with the shipping lines.

Classification	Number of Ports	Number of Observations
Hinterland Competition		
Low	35	363
Moderate	21	136
High	11	92
Transshipment Competition		
Yes	16	133
No	39	458
Regulation		
Ministry of Transport/ Shipping	10	137
Regulator	6	45
Port Authority	11	147
No Regulation	18	262

Table 4.5: Number of ports and observations in each classification of competition and regulation

Contextual variables as denoted by $z2_{j,it}$ in Model 2 are used to evaluate the combined effects of ownership, competition, and regulation on the technical efficiency of the container ports in the sample. Transshipment competition is treated separately, and hinterland competition is divided into two categories to estimate the combined effects. Hinterland competition is assumed to be low if the number of container ports within a radius of 1,000 kilometres is less than or equal to 10. Hinterland competition is assumed to be high if the number of container ports within a radius of 1,000 kilometres is greater than 10. Ownership is divided into two categories as before, with minority private ports having less than or equal to 50% private operators and majority private ports having more than 50% private operators. Regulation is treated as before with four categories, namely no regulation, regulation by the ministry of transport/shipping, regulation by the port authority or regulation by a separate regulatory institution. As can be seen from Table 4.6, we get 13 levels after combining ownership, hinterland competition, and regulation. We have no observations for a minority private port that has high competition and is regulated by the ministry of transport/shipping; a minority private port that has high competition and is regulated by the port authority; and a majority private port that has high competition and is regulated by a separate regulatory institution. We have only five observations for a minority private port that has high competition and is regulated by a separate regulatory institution. Nevertheless, this is sufficient in order for us to make the estimations.

We also perform sensitivity analyses of the interaction effects on technical efficiency by varying the hinterland competition levels and catchment area. The results are presented in Appendix 4.B and 4.C. In Appendix 4.B, for the combined effects model, hinterland competition is assumed to be low if there are between zero to five container ports within a radius of 1,000 kilometres, and hinterland competition is assumed to be high if there are more than five container ports within a radius of 1,000 kilometres. In Appendix 4.C, the catchment area has been reduced to 500 kilometres. For the combined effects model, hinterland competition is assumed to be low if there are between zero to five container ports within a radius of 500 kilometres, and hinterland competition is assumed to be high if there are more than five container ports within a radius of 500 kilometres.

Hinterland Competition	Ownership	MOT/S	Regulator	PA	NR	Total
Low	**Minority Private**	82	27	56	40	205
High		0	5	0	133	138

Low	**Majority Private**	34	13	80	31	158
High		21	0	11	58	90
Total		137	45	147	262	591

Table 4.6: Number of observations in each classification of the combination of the contextual variables

We also include country-fixed effects in both models to account for country-level heterogeneity and to get estimates of the output level on average by container ports in each one of the countries included in the sample. After the estimations, we also compute the elasticities of the output with respect to each input, the returns to scale, and the technical change. The elasticities $\varepsilon_{k,it}$, the returns to scale RTS and the technical change TC can be respectively calculated as follows:

$$\varepsilon_{k,it} = \beta_k + \beta_{kt}t + \sum\nolimits_j \beta_{jk} lnx_{j,it}$$

$$RTS = \sum\nolimits_k \overline{\varepsilon_{k,it}}$$

$$TC = \beta_t + \beta_{t^2}t + \sum\nolimits_k \beta_{kt} lnx_{k,it}$$

The output elasticity is computed as the partial derivative of the output with respect to each input. The returns to scale is computed as the summation of the individual elasticities of the output with respect to each input. The technical change is computed as the partial derivative of the output with respect to time. The βs in the above equations are the coefficients estimated via maximum likelihood estimation of the SFA models.

4.4. Results

Table 4.7 contains the results of the SFA models. In Table 4.7, the first model evaluates the individual effects of the contextual variables, and the second model evaluates the combined effects of the contextual variables. While the coefficients of the inputs and their combinations provide useful insights, we will focus only on the elasticities of the output with respect to the individual inputs. From Model 1, the mean elasticity of the output with respect to (w.r.t.) berth length is 0.10, meaning a 1% increase in berth length leads to a 0.10% increase in output. The mean output elasticity w.r.t. the terminal area is 0.33 and the mean output elasticity w.r.t. the number of cranes is 0.57. From Model 2, the mean elasticity of the output w.r.t. the berth length is 0.13, the mean output elasticity w.r.t. terminal area is 0.22, and the mean output elasticity w.r.t. the number of cranes is 0.56.

Variables	**Model 1**		**Model 2**	
	Coefficient	**Std. Error**	**Coefficient**	**Std. Error**
Intercept	-7.33	2.27**	-5.53	1.33***
ln(BL)	0.079	0.89	-0.88	0.91
ln(TA)	2.06	0.64**	2.38	0.57***
ln(NC)	2.03	0.55***	2.29	0.48***
ln(BL)*ln(TA)	0.47	0.11***	0.61	0.11***
ln(BL)*ln(NC)	-0.15	0.10	-0.36	0.098***
ln(TA)*ln(NC)	-0.16	0.055**	-0.10	0.052
$(\ln(BL))^2$	-0.69	0.16***	-0.68	0.15***
$(\ln(TA))^2$	-0.37	0.10***	-0.50	0.010***
$(\ln(NC))^2$	0.44	0.084***	0.56	0.077***
t	0.088	0.046	0.086	0.043*

t^2			-0.0035	0.00078^{***}	-0.0035	0.0007^{***}
t*ln(BL)			-0.029	0.0066^{***}	-0.035	0.0066^{***}
t*ln(TA)			0.011	0.0054^{*}	0.013	0.0053^{*}
t*ln(NC)			0.015	0.0048^{**}	0.021	0.0042^{***}
Z Intercept			-2.32	0.69^{***}		
Ownership – Majority Private			Base Case			
Ownership – Minority Private			0.67	0.15^{***}		
Competition - Low			1.25	0.38^{***}		
Competition - Moderate			1.43	0.38^{***}		
Competition - High			Base Case			
Transshipment Competition - No			Base Case			
Transshipment Competition - Yes			-0.96	0.24^{***}		
Regulation – MOT/ S			0.70	0.20^{***}		
Regulation - Regulator			-2.85	0.77^{***}		
Regulation – PA			-0.59	0.22^{**}		
Regulation – No Regulation			Base Case			
Z Intercept					-1.33	0.31^{***}
Transshipment Competition - No					Base Case	
Transshipment Competition - Yes					-0.43	0.16^{**}
Majority Private	Low Competition	MOT/S			2.87	0.39^{***}
		Regulator			-3.13	0.91^{***}
		PA			1.27	0.35^{***}
		NR			-2.67	0.73^{***}
	High Competition	MOT/S			3.73	0.47^{***}
		PA			1.99	0.37^{***}
		NR			Base Case	
Minority Private	Low Competition	MOT/S			1.98	0.34^{***}
		Regulator			0.75	0.40
		PA			1.29	0.33^{***}
		NR			2.32	0.31^{***}
	High Competition	Regulator			1.90	0.49^{***}
		NR			1.75	0.30^{***}
Country Fixed Effects			Yes		Yes	
σ^2			0.81	0.15^{***}	0.29	0.029^{***}
γ			0.97	0.01^{***}	0.93	0.016^{***}
log likelihood value			-253.18		-192.22	
Average Efficiency			0.68		0.63	
Note:					$^{*}p<0.05$; $^{**}p<0.01$; $^{***}p<0.001$	

Table 4.7: SFA Results

Appendix 4.D depicts the elasticities from Model 1 plotted against the respective input. The graphs show that the output elasticity w.r.t. the berth length and terminal area are downward sloping when plotted against the respective input. These values also become negative for larger berth lengths. This shows that these elasticities attain lower values for larger berth lengths and terminal areas. The output elasticity w.r.t. the number of cranes is upward sloping, meaning that the elasticities increase with the number of cranes with larger ports having a highly elastic output w.r.t. the number of cranes.

Appendix 4.D also depicts the elasticities from Model 2 plotted against the respective input. As with the individual effects model, the elasticities in the combined effects model are downward sloping when plotted against the berth length and terminal area and are upward sloping for the number of cranes. Similar to the individual effects model, the elasticities become negative for larger berth lengths and are positive and highly elastic when the number of cranes in the container port increases.

The elasticities from the individual and combined effects models can be used to obtain the returns to scale. From Model 1, the returns-to-scale value is one, indicating that the container ports exhibit constant returns to scale. From Model 2, the returns-to-scale value is 0.91, indicating that the container ports exhibit mild decreasing returns to scale. So depending upon the model chosen, the ports exhibit either constant or a mild decreasing returns to scale from our analysis of elasticities. These values can be interpreted as the long-run returns to scale because all factors of production for the container ports vary during the 25 years considered in our analysis. These results align with the findings of Notteboom et al. (2000) and Cullinane et al. (2006), who find that ports are operating with constant returns to scale. Moreover, our results are also in line with the findings of Liu (1995), Yan et al. (2009), and Medda and Liu (2013), who find that ports are operating with decreasing returns to scale.

The coefficients of time can be used to estimate the technical change experienced by the ports. We find that the ports have experienced a low technical change during the analysis period. The technical change is 1.2% in Model 1 and 2% in Model 2. This means that the output has increased at 1.2% per year in Model 1 and 2% per year in Model 2. Nevertheless, Figure 4.2 shows that this rate of change is not constant. The left panel in Figure 4.2 shows that the rate of change of output with respect to time is downward sloping, meaning that output is increasing with a decreasing rate over time. The right panel in Figure 4.2 plots the technical change w.r.t. the output. The results obtained here are ambiguous and the first model shows that the technical change decreases with the output, while the second model shows that the technical change is constant w.r.t. the output. As a result, we cannot arrive at conclusions as to whether smaller or larger ports have a higher amount of technical change. The outcome depends mainly upon the chosen model.

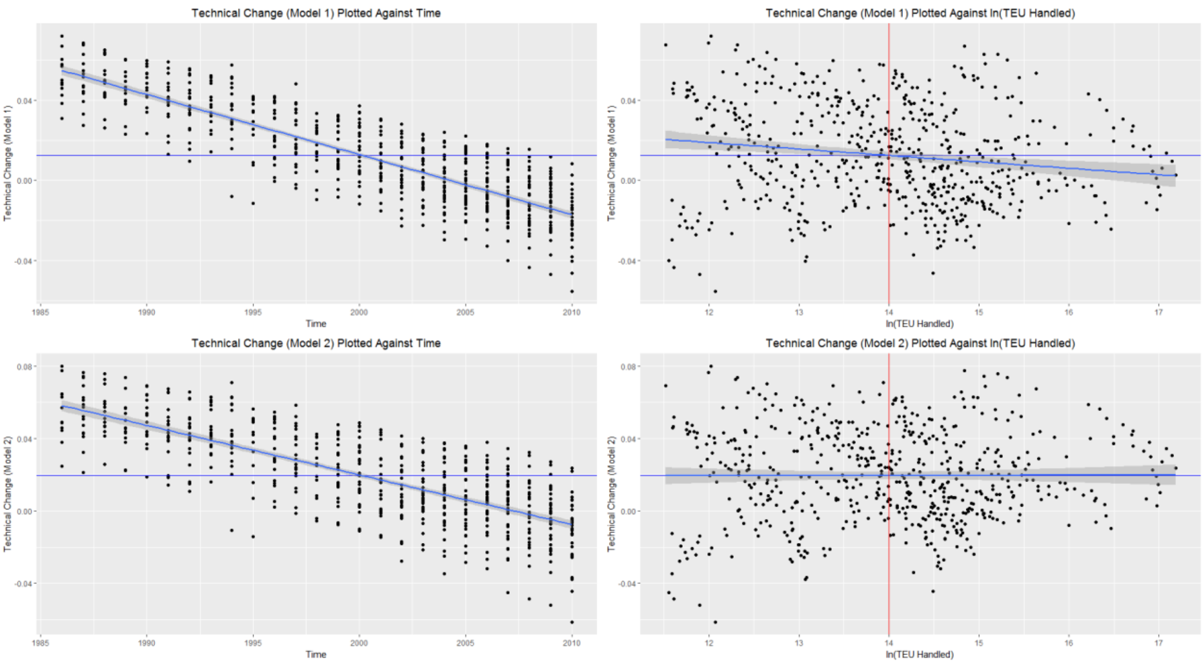


Figure 4.2: Technical change plotted against time and the output

The two models have slightly different mean efficiency estimates. It is 68% in Model 1 and 63% in Model 2. Figure 4.3 shows the average annual technical efficiency. Although there are fluctuations, mainly because we have an unbalanced panel dataset with missing observations, we observe an increase in the annual average technical efficiency. While Model 2 has a 5%

increase in annual average technical efficiency from 65% in 1986 to 70% in 2010, Model 1 has a slightly higher increase in the annual average technical efficiency. The annual average technical efficiency increases by 11% in Model 1 from 66% in 1986 to 77% in 2010. We infer that the individual effects model shows a higher increase in the annual average technical efficiency than the combined effects model.

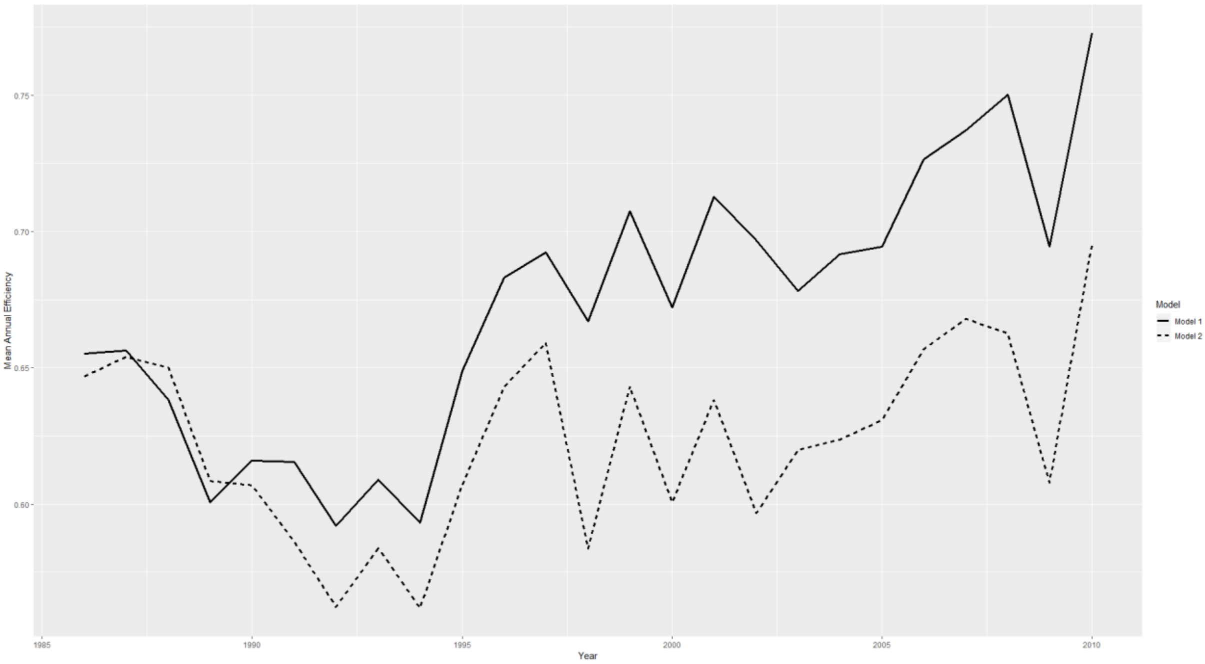


Figure 4.3: Average annual technical efficiency

Figure 4.4 contains the box plots of the efficiencies of the ports classified by models. We observe that there is a significant variation in the rankings of some container ports depending upon the chosen model. More specifically, the combined effects used to measure the impact of the contextual variables on technical efficiency result in a significant variation in the rankings for some container ports. For example, Busan obtains higher rankings in Model 1 but is among the least technically efficient in Model 2. As a result, the combined effects of the contextual variables significantly impact technical efficiency and hence produce slight differences in the rankings of the technical efficiency of some container ports (see Figure 4.4). It should however be noted that the rankings are quite similar across the two models except for some container ports.

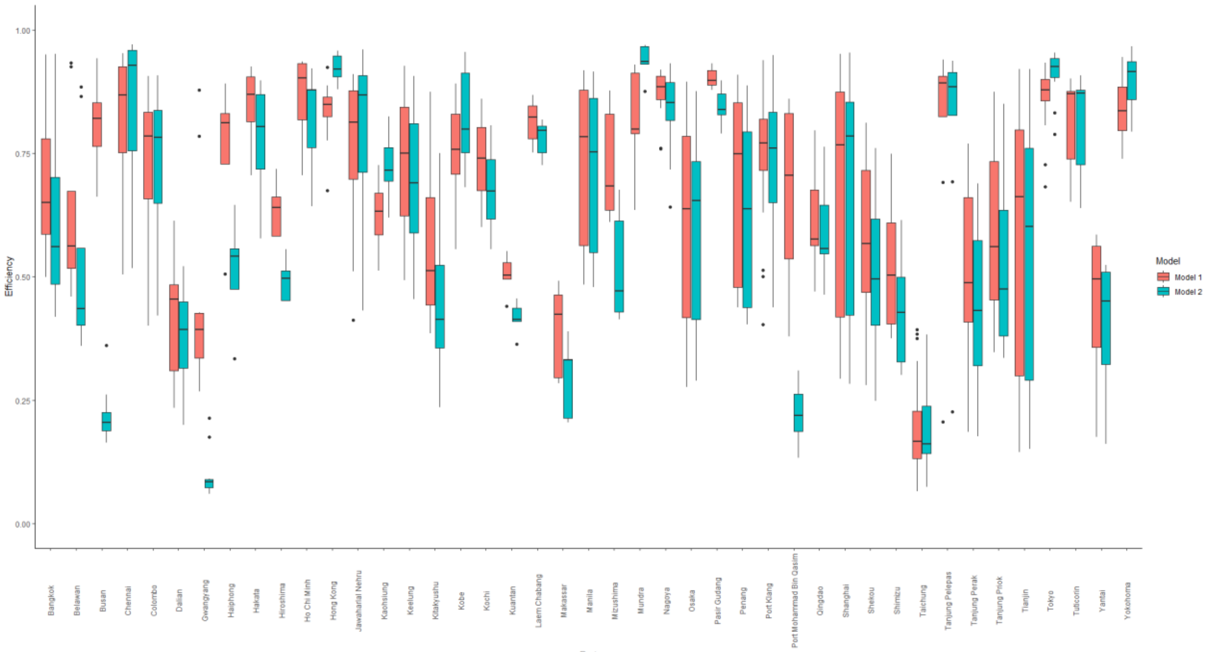


Figure 4.4: Efficiency by port

First, we discuss Hypotheses 1-4 with the SFA regression of individual effects of the contextual variables on technical efficiency, see Model 1 in Table 4.7. This model relates our findings to the literature. In general, ports with a higher share of private ownership, high hinterland, and transshipment competition are, on average, more efficient than other ports. These findings confirm **Hypothesis 1**, **Hypothesis 2**, and **Hypothesis 3**. But we reject **Hypothesis 4** because the coefficients indicate that regulation by an independent regulator and, with weaker significance, port-authority-regulation increase efficiency.

Concerning Hypothesis 1, which states that private participation and the landlord seaport model have a positive impact on technical efficiency, our findings are in line with Cullinane et al. (2006), Chang and Tovar (2014b), Wanke et al. (2011) and Lopez-Bermudez et al. (2019a). The second fits to Sarriera et al. (2013), Trujillo et al. (2013), Serebrisky et al. (2016) and Suarez-Aleman et al. (2016). Hypothesis 2 refers to the efficiency-enhancing property of high hinterland competition. Therefore, we argue that port policy should promote hinterland competition, as has been argued by Merkel (2018). Our findings concerning Hypothesis 3 align with Cullinane et al. (2006), Notteboom et al. (2000), and Sarriera et al. (2013), who also provide evidence that transshipment competition increases technical efficiency.

The more interesting case is the role of regulation. Our results provide evidence to reject **Hypothesis 4** that deregulation positively impacts the technical efficiency of container ports. Our finding contrasts Cullinane et al. (2002) and Cullinane and Song (2003). However, since we distinguish different types of regulation, we can qualify the deregulation issue. While Hypothesis 4 holds if we consider MOT/S regulation, it fails concerning ports regulated by an independent regulator or the port authority. They are significantly more technically efficient than ports without regulation. This result is much stronger for independent regulators.

Our intuition for the less efficient regulation by the ministry of transport/shipping is the following: the regulation by the ministry of transport/shipping may lead to regulatory capture. The ministry of transport/shipping may have objectives other than improving technical efficiency. It may focus on increasing output and employment at the container ports. This could have adverse consequences on the technical efficiency of the container ports, which is what our results indicate.

The main task of this paper is to get a more precise understanding of the efficiency impact of port governance. Therefore, we look at the interaction of ownership, competition, and regulation type. The column Model 2 in Table 4.7 displays the results. To reduce complexity, we do not consider interaction terms with transhipment competition. It is treated separately, and we find that container ports which face transshipment competition are significantly more technically efficient than container ports without transshipment competition. These results are in line with the results obtained by Cullinane et al. (2006), Notteboom et al. (2000) and Sarriera et al. (2013) and also with the results obtained in our individual effects Model 1.

In Model 2, a majority private port that faces high hinterland competition and has no regulation serves as the base case. Most other combinations of the contextual variables lead to lower technical efficiency compared to this base case. There are two exceptions referring to a majority private port with low hinterland competition. While one would expect that regulation is an instrument to substitute competition and, thus, increase efficiency, our finding is that MOT/S and PA regulation is not working in that sense, but regulation by an independent regulator is. Surprisingly, the latter and no regulation increase technical efficiency above the base case's efficiency level. Hence, we reject **Hypothesis 5**, which states that a majority-private container port that faces high hinterland competition and has no economic regulation is the most technically efficient.

What may be a reason why efficiency is higher with low than with high competition? Intuition is the following: Excessive entry may result in overcapacity, implying that high competition reduces efficiency. This result is in line with the theory of excessive entry (Mankiw and Whinston, 1986), wherein entrants steal business from incumbents and lower the output per firm resulting in loss of social welfare and reduced firm efficiency. Empirical research on excessive entry includes Berry and Waldfogel (1999) for radio broadcasting, Hsieh and Moretti (2003) for the real estate industry, Hortacsu and Syverson (2004) for the mutual fund industry, and Davis (2006) for the motion picture exhibition market. Hortacsu and Syverson (2004) show that excessive entry harms overall social welfare in the mutual fund industry. Berry and Waldfogel (1999) and Davis (2006) show that excessive entry results in business stealing, which leads to a loss in overall social welfare and overall social inefficiency in the radio broadcasting and motion picture exhibition markets, respectively. Moreover, Hsieh and Moretti (2003) show that the business-stealing effect leads to overall social inefficiency and reduces the productivity of real estate agents. Usually, one may expect that regulation can increase efficiency in that case. However, MOT/S and PA regulation reduces efficiency even more in our study. Whether independent regulation is an instrument to lower this market-induced inefficiency cannot be stated since there is no such case in our database (see Table 4.6).

The independent regulator is a very efficient way of regulating container ports if there is low hinterland competition. It works in this case like no regulation for majority-private ports and is even more efficiency-enhancing for minority-private ports than no regulation. However, while Model 1 suggests that an independent regulator increases efficiency on average, our combined model reveals that this holds only for majority-private ports that face low hinterland competition.

Eventually, our findings suggest that low competition is better than high competition in the case of majority-private container ports but is worse with minority-private container ports. Hence, in contrast to Model 1, there is no general impact of competition we can identify when considering interaction terms.

These results provide policymakers with insights on the importance of independent economic regulators in promoting the technical efficiency of container ports. Our results also provide policymakers with insights on the relevance of hinterland competition, transshipment competition and private participation in promoting the technical efficiency of container ports. Moreover, from the combined effects model, policymakers can gain insights on how excessive entry can have an adverse consequence on the technical efficiency of container ports.

Appendix 4.B presents the results of the sensitivity analysis wherein the hinterland competition levels have been changed as has been described in the previous section. With respect to the individual effects model, while the results are very similar to the base model, there is no significant difference in the technical efficiency of different hinterland competition levels. However, they exhibit the same signs as in the base model. The results of the combined effects model are also very similar to the base case. However, a majority private port that faces low hinterland competition and has no economic regulation is as technically efficient as the base case. Appendix 4.C presents the results of the sensitivity analysis wherein the catchment area used to measure hinterland competition has been reduced to 500 kilometres as has been described in the previous section. With respect to the individual effects model, the results are very similar to the base case. However, a port which faces moderate hinterland competition is as technically efficient as a port which faces high hinterland competition and regulation by the ministry of transport/shipping leads to the same technical efficiency as having no economic regulation. It should be noted that in these cases, the signs of these coefficients are the same as in the base model. With respect to the combined effects model, a majority private port that faces low hinterland competition and has no economic regulation is as technically efficient as the base case. Apart from this difference, the results of the combined effects model in Appendix 4.C are also very similar to the results of the base case. As a result, we infer that the estimates obtained from the base models presented in this section are robust because they are very similar to the estimates obtained in the sensitivity analyses.

4.5. Conclusions and Future Directions

This paper analyses the impact of governance on the technical efficiency of container ports. We use an unbalanced panel dataset containing 43 Asian ports observed between 1986 and 2010 to test our hypotheses. We find that the sample ports exhibit constant or a mild decreasing returns to scale. We also observe that they experience a low amount of technical change with output increasing at a decreasing rate over time. The mean efficiency estimates range from 63% to 68% depending upon the chosen model. This shows that there is significant scope for efficiency improvement among the sample Asian container ports. The annual average technical efficiency has increased over time ranging between 5% and 11% between 1986 and 2010. We observe that there is a slight variation in the efficiency rankings of the container ports across the two models.

To the best of our knowledge, this is the first paper to analyse the impact of all vital governance-related factors on the technical efficiency of container ports. Moreover, to the best of our knowledge, this is also the first contribution to analyse the impact of both hinterland and transshipment competition on the technical efficiency of container ports. From the individual effects model, we find that private participation, hinterland competition and transshipment competition have a significant positive impact on the technical efficiency of the container ports. We hence propose that port policy should aim at promoting the landlord port model and it should encourage hinterland and transshipment competition between seaports. Regulation by an independent regulator is shown to be the most efficiency enhancing and we hence propose that setting up of independent regulators for port regulation can best address the problems related to market power of ports and terminal operators.

This paper also contributes to the literature by analysing the combined impact of governance-related contextual variables on the technical efficiency of container ports. This sheds light on the impact that excessive entry and independent economic regulators have on the technical efficiency of container ports. From the combined effects models, that is our main focus, a majority private port that faces high hinterland competition and has no economic regulation serves as the base case. We find that most other combinations of ownership, hinterland competition, and economic regulation lead to lower technical efficiency than the base case, with two exceptions. The first exception is a majority private port that faces low hinterland competition and has no economic regulation. The second exception is a majority private port that faces low hinterland competition and is regulated by an independent regulator. This could be because there is excessive entry leading to overcapacity. In comparing the two cases that result in higher technical efficiency than the base case, we find that for a majority private port with low hinterland competition, having economic regulation by an independent regulator leads to a significantly higher technical efficiency as opposed to having no economic regulation. As a result, along with the setting up of independent regulators for seaports, policymakers should also ensure that there is no excessive entry of ports and terminal operators. While a certain degree of competition can be efficiency enhancing, excessive entry can lead to destructive competition which can harm the technical efficiency of container ports. This is what our results indicate and we propose that policymakers should promote optimal entry based on demand from the surrounding catchment areas and shipping lines, which can promote hinterland and transshipment competition that is efficiency enhancing.

For future research, we propose that the data collection on labour and variable inputs such as energy will lead to a better representation of the production process of container ports. Data collection at the level of the container terminal is also an avenue for future research. Inclusion of externalities in the production process will lead to a better estimation of the production functions. Future research can also focus on better capturing the effect of competition on technical efficiency by conducting a route level analysis to get a measure of route level overlap between container ports or terminals. Future research can also estimate cost frontiers for the same sample of container ports. Finally, measuring the impact of improved port efficiency and effectiveness on the surrounding regions and economic welfare is also an avenue for future research.

Appendix 4.A. Additional SFA Models

Variables	Model 3		Model 4	
	Coefficient	Std. Error	Coefficient	Std. Error
Intercept	0.94	1.21	-0.46	0.99
ln(BL)	-2.59	0.89**	-2.40	0.89**
ln(TA)	3.44	0.54***	2.94	0.49***

ln(NC)	-0.19	0.57	0.90	0.55
ln(BL)*ln(TA)	0.64	0.10***	0.59	0.10***
ln(BL)*ln(NC)	-0.25	0.10*	-0.27	0.11*
ln(TA)*ln(NC)	0.12	0.07	-0.012	0.058
$(\ln(BL))^2$	-0.64	0.14***	-0.53	0.14***
$(\ln(TA))^2$	-0.64	0.095***	-0.55	0.092***
$(\ln(NC))^2$	0.15	0.10	0.42	0.10***
t	0.057	0.004***	0.047	0.0052***
t^2	-0.0042	0.0006***	-0.0046	0.00075***
t*ln(BL)	-0.0064	0.008	-0.028	0.0076***
t*ln(TA)	0.0022	0.004	0.016	0.0045***
t*ln(NC)	0.022	0.004***	0.022	0.0047***
Ownership – Majority Private			Base Case	
Ownership – Minority Private			0.31	0.045***
Competition - Low			0.43	0.078***
Competition - Moderate			0.29	0.059***
Competition - High			Base Case	
Transshipment Competition - No			Base Case	
Transshipment Competition - Yes			-0.025	0.057
Regulation – MOT/S			-0.17	0.095
Regulation - Regulator			-0.30	0.12*
Regulation – PA			-0.70	0.10***
Regulation – No Regulation			Base Case	
Country Fixed Effects	Yes		No	
σ^2	0.67	0.13***	0.42	0.036***
γ	0.91	0.022***	0.85	0.020***
log likelihood value	-96.17		-132.56	
Average Efficiency	0.51		0.52	
Note:			$^{*}p<0.05$; $^{**}p<0.01$; $^{***}p<0.001$	

Appendix 4.B. Sensitivity Analysis of SFA Models with Changes to the Hinterland Competition Levels

Variables	Model 1		Model 2	
	Coefficient	Std. Error	Coefficient	Std. Error
Intercept	-5.66	1.71***	-12.63	3.61***
ln(BL)	0.047	0.89	0.14	0.88
ln(TA)	1.79	0.54***	3.12	0.84***
ln(NC)	2.18	0.54***	0.94	0.66
ln(BL)*ln(TA)	0.48	0.12***	0.49	0.10***
ln(BL)*ln(NC)	-0.16	0.11	-0.32	0.10**
ln(TA)*ln(NC)	-0.17	0.056**	0.0088	0.072
$(\ln(BL))^2$	-0.70	0.17***	-0.65	0.15***
$(\ln(TA))^2$	-0.35	0.098***	-0.50	0.11***
$(\ln(NC))^2$	0.47	0.086***	0.46	0.083***
t	0.078	0.048	0.13	0.044**
t^2	-0.0032	0.00075***	-0.0033	0.00065***
t*ln(BL)	-0.025	0.0069***	-0.029	0.0065***

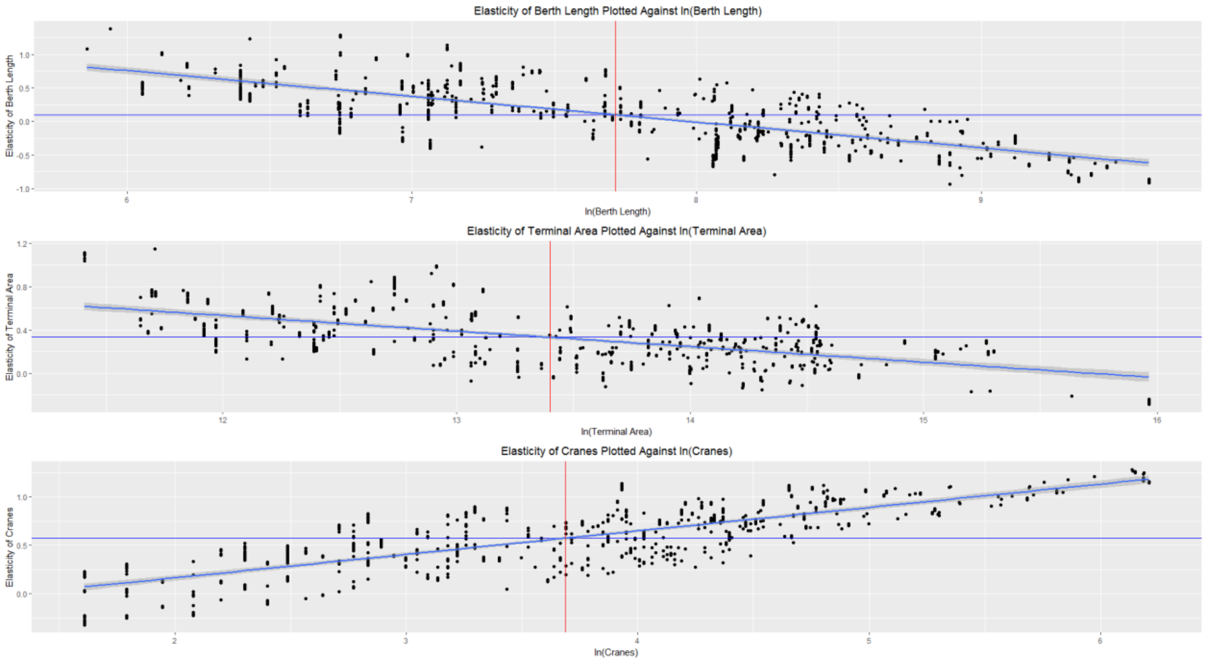
t*ln(TA)			0.010	0.0056	0.0073	0.0052
t*ln(NC)			0.011	0.0049*	0.017	0.0045***
Z Intercept			-1.15	0.41**		
Ownership – Majority Private			Base Case			
Ownership – Minority Private			0.53	0.15***		
Competition - Low			0.36	0.26		
Competition - Moderate			0.035	0.18		
Competition - High			Base Case			
Transshipment Competition - No			Base Case			
Transshipment Competition - Yes			-1.16	0.26***		
Regulation – MOT/ S			0.58	0.23*		
Regulation - Regulator			-3.25	0.89***		
Regulation – PA			-0.86	0.29**		
Regulation – No Regulation			Base Case			
Z Intercept					-4.06	0.98***
Transshipment Competition - No					Base Case	
Transshipment Competition - Yes					-0.53	0.16***
		MOT/S			5.40	0.99***
	Low	Regulator			-7.62	2.36**
	Competition	PA			3.78	0.92***
Majority		NR			1.31	(1.00)
Private		MOT/S			4.26	0.96***
	High	Regulator			-0.81	0.96
	Competition	PA			4.00	0.90***
		NR			Base Case	
		MOT/S			4.46	0.93***
	Low	Regulator			3.13	0.83***
Minority	Competition	PA			3.14	0.79***
Private		NR			5.89	1.02***
	High	Regulator			2.34	0.77**
	Competition	PA			4.54	0.97***
		NR			4.42	0.93***
Country Fixed Effects			Yes		Yes	
σ^2			0.81	0.15***	0.42	0.045***
γ			0.96	0.010***	0.95	0.013***
log likelihood value			-257.22		-193.95	
Average Efficiency			0.69		0.68	
Note:					*p<0.05; **p<0.01; ***p<0.001	

Appendix 4.C. Sensitivity Analysis of SFA Models with Changes to the Catchment Area

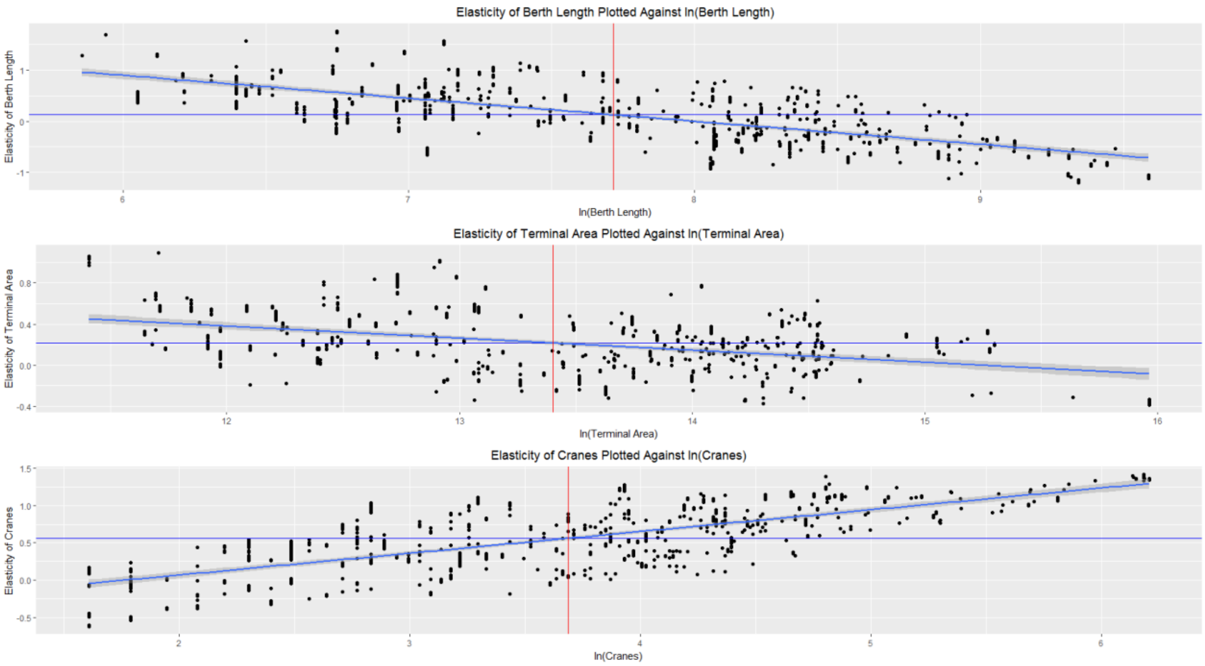
Variables	Model 1		Model 2	
	Coefficient	Std. Error	Coefficient	Std. Error
Intercept	-6.00	1.91**	-12.30	3.42***
ln(BL)	-0.043	0.89	-0.41	0.92
ln(TA)	1.89	0.59**	3.37	0.82***
ln(NC)	2.28	0.52***	0.97	0.65
ln(BL)*ln(TA)	0.47	0.11***	0.56	0.11***
ln(BL)*ln(NC)	-0.18	0.10	-0.41	0.097***
ln(TA)*ln(NC)	-0.17	0.052**	0.039	0.069
$(\ln(BL))^2$	-0.66	0.16***	-0.65	0.14***
$(\ln(TA))^2$	-0.35	0.10***	-0.57	0.12***
$(\ln(NC))^2$	0.47	0.083***	0.50	0.082***
t	0.065	0.047	0.14	0.045**
t^2	-0.0032	0.00077***	-0.0036	0.00067***
t*ln(BL)	-0.027	0.0066***	-0.033	0.0062***
t*ln(TA)	0.012	0.0055*	0.0091	0.0053

t*ln(NC)			0.013	0.0048^{**}	0.019	0.0048^{***}
Z Intercept			-1.79	0.59^{**}		
Ownership – Majority Private			Base Case			
Ownership – Minority Private			0.66	0.15^{***}		
Competition - Low			1.17	0.34^{***}		
Competition - Moderate			0.50	0.25		
Competition - High			Base Case			
Transshipment Competition - No			Base Case			
Transshipment Competition - Yes			-0.85	0.25^{***}		
Regulation – MOT/ S			0.26	0.17		
Regulation - Regulator			-1.02	0.28^{***}		
Regulation – PA			-3.24	0.87^{***}		
Regulation – No Regulation			Base Case			
Z Intercept					-4.02	0.87^{***}
Transshipment Competition - No					Base Case	
Transshipment Competition - Yes					-0.44	0.14^{**}
Majority Private	Low Competition	MOT/S			5.44	0.88^{***}
		Regulator			-4.53	1.46^{**}
		PA			4.16	0.85^{***}
		NR			1.12	0.88
	High Competition	PA			1.36	0.97
		NR			Base Case	
Minority Private	Low Competition	MOT/S			4.60	0.87^{***}
		Regulator			3.26	0.79^{***}
		PA			3.23	0.76^{***}
		NR			4.86	0.86^{***}
	High Competition	PA			5.15	0.92^{***}
		NR			4.48	0.85^{***}
Country Fixed Effects			Yes		Yes	
σ^2			0.81	0.16^{***}	0.32	0.025^{***}
γ			0.97	0.010^{***}	0.92	0.015^{***}
log likelihood value			-253.83		-197.49	
Average Efficiency			0.68		0.65	
Note:					$^{*}p<0.05$; $^{**}p<0.01$; $^{***}p<0.001$	

Appendix 4.D. Elasticities Plotted Against the Respective Input



Individual Effects



Combined Effects

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Chapter 5

Conclusions

This thesis has analysed how governance impacts the performance of airports and seaports. More specifically, Chapter 2 has analysed how economic regulation impacts the performance of airports by conducting a literature review of the topic. Chapter 3 has analysed how governance impacts the performance of major Indian seaports. This paper uses a two stage methodology. The first stage estimates a non-oriented variable returns to scale slacks based measure of technical efficiency. The second stage performs fixed effects regression to explain the impact of the governance-related variables on the technical efficiency of the major Indian seaports. Chapter 4 has analysed the impact of governance on the technical efficiency of container ports from the Far East and Asian region. This is done by employing SFA in order to estimate a production frontier. The impact of the governance-related variables is estimated using a single step procedure which allows the estimation of the production frontier as well as the estimation of the impact of the governance-related variables. This chapter focuses on some policy recommendations arising from this research.

Our literature review on the impact of airport regulation on performance reveals that incentive and light-handed regulation are preferable in comparison to rate-of-return regulation. As there has been substantial reform in airport regulation, regulators should be encouraged to apply incentive or light-handed regulation instead of rate-of-return regulation. Incentive regulation has many advantages over rate-of-return regulation. As analysed by Beesley and Littlechild (1989), RPI-X regulation has an exogenous risk period, it is a forward looking approach, the regulator has more degrees of freedom and the regulator has less requirement to explain. As a result of these four differences, the regulator has a higher bargaining power which results in incentives and efficiency motives for the firm being regulated. Moreover, as incentive regulation regulates only the price level and not the price structure, it provides incentives for airports to pursue Ramsey pricing and peak pricing (Bradley and Price, 1988; Knieps, 2008). On the other hand, rate-of-return regulation sets incentives for rather uniform price structures. With a negotiate-arbitrate model in place and with a credible threat of re-regulation, light-handed regulation also has some advantages over rate-of-return regulation. It is less costly in comparison to other forms of regulation, it does not require much information and the regulated utility has no incentives to engage in opportunistic behaviour, it is better than having an imperfect form of regulation, it is less susceptible to problems arising from corruption and regulatory capture, and regulators do not control the industry structure and conduct thus having no dampening effect on new entry (Bollard and Pickford, 1995). Meanwhile, rate-of-return regulation has some drawbacks because it can lead to cost inefficiency, overcapitalization, financial inefficiency and high administrative costs (Liston, 1993).

In the case of price-cap regulation, we find that a dual-till price-cap is preferable to a single-till price-cap. Even though a single-till price-cap leads to lower aeronautical charges and higher aeronautical output in comparison to a dual-till price-cap, a dual-till price-cap is preferable from an efficiency perspective because it incentivizes the airport to be more innovative in order to earn higher commercial revenues. Moreover, Niemeier (2021) reviews the theoretical literature to show that a dual-till is preferable to a single-till. He argues that imposing a single-till on an airport might lead to opportunistic behaviour by the regulator. He also argues that at a congested airport, a dual-till encourages peak and off-peak pricing while a single-till distorts competition and leads to higher scarcity rents for airlines. It should however be noted that dual-till price-caps are desirable only in markets with no competition and in markets with competition, no regulation or light-handed regulation may be preferable (Adler and Liebert, 2014). In markets with no competition, a dual-till price cap may be preferable to light-handed regulation because light-handed regulation does not necessarily constrain airport charges.

With respect to slot allocation, Pels et al. (2003) find that slot coordinated European airports are more technically efficient in comparison to European airports which are not slot coordinated. In comparing slot allocation to queuing, Jacquillat and Odoni (2018) find that slot allocation is superior to queuing in relation to capacity, delay and congestion management. However, in the EU, slot allocation is done administratively and this has some drawbacks. We propose that slot allocation has to be done based on economic principles rather than on an administrative basis. Instruments such as secondary slot trading, higher runway charges and slot auctions can enhance allocative efficiency (Guiomard, 2018).

We also identify some avenues for future research. With respect to rate-of-return regulation, future research can focus on whether it provides no incentive for airports to pursue peak pricing. Future research can also focus on whether rate-of-return regulation leads to the Averch and Johnson (1962) effect, gold plating and cost padding. With respect to price-cap regulation, future research can focus on whether it provides congested airports with an incentive to pursue peak pricing. Future research can also focus on whether a single-till price-cap provides weak incentives for airports to earn commercial revenues. Future research should also focus on whether price-cap regulation leads to under-investment, which leads to a deterioration in the quality of service. Other weaknesses of price-cap regulation have also not been analysed in the literature. For example, future research could focus on whether some airlines are not served due to the presence of a price-cap and whether the lack of rate hearings lowers airport efficiency. Price-cap regulation is argued to be superior to rate-of-return regulation. However, further research can focus on sources of inefficiency in rate-of-return regulation and sources of efficiency gains in price-cap regulation as has been analysed in Averch and Johnson (1962), Liston (1993), Armstrong et al. (1994) and Beesley and Littlechild (1989). With respect to light-handed regulation, future research can focus on whether efficiency oriented light-handed regulation is superior to cost-based light handed regulation. Future research can also focus on whether the negotiate/arbitrate model is superior to the review/sanction approach. Slot allocation and queuing have not been analysed from a benchmarking perspective and the right slot capacity limit and its implications for airport efficiency have also not been analysed in the literature. Investment regulation has also not been analysed in depth in the benchmarking literature that analyses the performance impact of regulation on airport performance. Lastly, further research could focus on airport regulation and performance in developing countries.

From the analysis of major Indian seaports, we find that most seaports have a scope for the improvement of technical efficiency. As the major Indian seaports are in competition with the non-major Indian seaports, further reform programs have to focus on the modernization of the major Indian seaports. This can prove beneficial in comparison to investing in new seaports, which can have a detrimental effect in case supply exceeds demand.

We find that specialization has a highly significant impact on technical efficiency. The current reform project underway for the Indian seaports is the Sagarmala project. This project focuses on port-facilitated industrialization. As specialization is found to be a significant driver of technical efficiency, the Sagarmala project could focus on enhancing the specialization of the major Indian seaports. The ports could derive the benefits of specialization through economies of scale. The project could establish industrial clusters based on the specialization potential of the seaports. The project could also enhance hinterland connectivity based on the requirements of the specialized seaports.

With respect to ownership, our results show that external stakeholder participation has a significant positive impact on the performance of the Indian seaports. This gives evidence that the landlord seaport model is conducive to enhanced performance. This could be because external stakeholders such as terminal operators have expertise in cargo handling and seaport operations due to their access to specialized technology and experience as has been argued by Cheon et al. (2010). As a result, we propose that it is best that the public port authorities focus on aspects such as monitoring and coordination while the specialized terminal operators can focus on cargo handling and seaport operations. We also suggest that the Ministry of Shipping has to ensure that terminal operators face terms and conditions that deems the concession contract viable over the duration of the project.

With respect to competition, we find that competition from non-major seaports from within a state as well as along the coast harms the technical efficiency of the major seaports. This is an interesting result and this could be because of the tiered governance framework for the major and the non-major seaports. Competition may lead to the business-stealing effect (Mankiw and Whinston, 1986) and the non-major seaports could be benefiting at the expense of the major seaports. We however argue that competition should not be curtailed. On the other hand, we propose that a common governance, institutional and regulatory framework should be put into place which will promote effective competition between the major and the non-major seaports.

With respect to regulation, we find that cost-based regulation by an independent regulator is superior to internal regulation by the port authority. As the port authority earns a rent which is a function of the terminal operator's revenues, an independent regulator is in a better position to regulate the seaports because the independent regulator is not susceptible to regulatory capture. However, there is scope for improvement in the regulatory process. Regulation could be reformed and price-cap regulation or light-handed regulation could be introduced based on an analysis of which form of regulation is more suitable to the context. Moreover, none of the non-major seaports are subject to economic regulation. We propose that this has to be further assessed and non-major seaports and terminal operators in the non-major seaports with significant market power need to be subject to the appropriate form of economic regulation. As the regulator has been using partial performance indicators, we also propose that data needs to be collected in order for the regulator to be able to use benchmarking techniques such as index number TFP, DEA and SFA in the regulatory mechanism. This should be done at the level of the terminal, port and port authority. Such techniques could be used to estimate the scale of rates, performance standards and tariff guidelines.

We now focus on the policy implications arising from our study on the technical efficiency of container ports from the Far East and Asian region. From the individual effects model, we find that private participation has a significant positive impact on the technical efficiency of the container ports. More specifically, we find that majority private ports are more technically efficient in comparison to minority private ports. As in the previous chapter, this gives evidence that the landlord seaport model enhances the technical efficiency of container ports.

Policymakers should be encouraged to promote private participation in container terminal operations with public port authorities divesting from container terminal operations.

From the individual effects model, we also find that hinterland competition and transshipment competition have a significant positive impact on container port technical efficiency. Container ports should thus be encouraged to compete with each other as this can have favourable outcomes. Ports that are transshipment hubs should be encouraged to compete with other transshipment ports for transshipment traffic. This in also beneficial in terms of the impact on technical efficiency. However, policymakers should ensure that there is optimal competition. Excessive hinterland and transshipment competition can harm efficiency as container ports will tend to overinvest in infrastructure.

From the individual effects model, we further find that economic regulation by an independent regulator is the most conducive to enhanced technical efficiency. Governments should thus set up independent regulators for container ports. Such regulators can make decisions without any political interference and hence can design regulatory frameworks that enhance the efficiency of container ports. Such institutions are the least susceptible to regulatory capture and can hence improve the performance of container ports.

In the combined effects model, a majority private port which faces high hinterland competition and has no economic regulation is taken as the base case. Most of the other combinations of the governance-related contextual variables lead to a significantly lower technical efficiency. However, a majority private port which faces low hinterland competition and has an independent regulator is significantly more technically efficient in comparison to the base case. These results are interesting and this could be happening because there is excessive entry resulting in competition that is above the optimal. We hence propose that along with the setting up of independent regulators, policymakers should ensure that there is no excessive entry. While a certain degree of competition is efficiency enhancing, excessive entry leads to the business-stealing effect (Mankiw and Whinston, 1986), which leads to container port infrastructure of competitors being utilized less than optimally, which can harm technical efficiency. Policymakers should thus ensure that entry is at the optimal level because this can then lead to competition which is efficiency enhancing.

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Declaration of Authorship

I hereby declare that this thesis contains no material which has been submitted, either in part or whole, for a degree at this or any other university or equivalent institution and that, to the best of my knowledge and belief, this thesis contains no material previously published or written by another person, except where due reference is made in the text of the thesis. The ideas, development and writing up of all the articles in the thesis were the principal responsibility of myself, the candidate. The inclusion of co-authors reflects the fact that the work came from active collaboration between researchers and acknowledges input into team-based research.

Bremen, 24-09-2022 ________________________

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