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How do economies of density in container handling operations affect ships' time and emissions in port? Evidence from Norwegian container terminals

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ABSTRACT

Efficient port services are prerequisites for competitive and sustainable maritime transports. This paper makes advances in studying the determinants of the time that ships spend in port and the associated emissions to air. We estimate a production model for cargo handling based on a unique dataset containing each port of call at the largest container terminals in Norway in 2014. In turn, we use auxiliary engine emission factors to estimate particulate matter and nitrogen oxide emissions from ships at berth, to determine how the corresponding damage costs of air pollution vary with container throughput, location, and terminal investments. We find that Norwegian container terminals operate under increasing returns to density. Small ships that unload few containers are far from reaping economies of density, leading to high marginal time requirements for container handling and consequently high marginal external costs. From a Pigouvian taxation perspective, port charges should therefore be regressive in the number of containers handled. Moreover, we find that the external costs of maritime transports are severely understated when port operations are ignored. Our model allows determining the marginal productivities of port facilities. Thereby, it is instrumental in designing port charges that are diversified according to the quantity of containers handled and the service quality (i.e., the speed of handling operations). Regarding contextual factors, we find that establishing high-frequent liner services improves the ship working rate, while simultaneous calls at a terminal impede productivity. The type of container (loading/unloading; empty/laden) also appears to influence the duration of ship working.

1. Introduction

Decision makers in Norway and Europe are determined to improve the economic and environmental performances of the transport system. Maritime transport receives attention by playing a pivotal role in international trade and thus in economic growth.[1] Moreover, intermodal transports are in general perceived as more environmental friendly than unimodal road transport, and to be instrumental in relieving road congestion. Norwegian and European freight transport policies therefore aim to strengthen the competitiveness of maritime and rail transports. In their 2011 white paper entitled *Roadmap to a Single European Transport Area –*

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[1] In the EU, 74 percent of all goods (measured by weight) entering and leaving Europe go by sea. In Norway, which is integrated in the European Single Market by being member of the European Economic Area agreement, maritime transport is the dominating mode for overseas freight transport.

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Towards a competitive and resource efficient transport system, the European Union (EU) lists 10 key objectives to achieve a competitive and resource efficient transport system. Among them is the target that 30% of road freight over 300 km should shift to other modes such as maritime and rail transports by 2030, and more than 50% by 2050.

The Norwegian transport agencies' latest freight analysis[2] supporting the National Transport Plan concluded that the competition among modes in Norway is limited. While maritime transport specializes in long-haul of bulk commodities and consumer goods, more than 90 percent of the cargo transported by road relates to construction and consumer goods that require only short-distance distribution. For maritime transport, the greatest potential for a mode shift lies in replacing long-haul road transport by container shipping at sea. Consequently, our study emphasizes container handling.

Ports constitute an essential component of the maritime transport chain. Carriers' operating costs are associated with the distance travelled and the time it takes to complete the voyage (Cullinane and Khanna, 2000); the latter being affected by the time spent in ports, loading and unloading cargo. Ultimately, carriers trade economies of ship size for additional time costs in ports (Jansson and Schneerson, 1987). Hence, studies such as Tongzon (2009) find port efficiency (also comprising the speed of cargo handling operations) to be among the determinants of carriers' and shippers' port choices.

Containerships are among the largest and fastest growing maritime emitters (Corbett et al., 2009). The time that these ships spend in port are crucial for the environmental impacts of maritime transport as their emissions whilst berthed can be the dominant source of urban air pollution (Cofala et al., 2007). This is especially relevant for Norway, where several of the largest ports are located near city centers. Schøyen and Bråthen (2015) find that containerships deployed in trade between Norway and continental European hub ports may spend 40–53% of their time in ports. While in port, most ships run auxiliary diesel engines to provide electricity for heating, refrigeration, cooling, lighting, and equipment, accompanied by air pollution. We emphasize nitrogen oxides (NO_x) and Particulate Matter (PM_{10}) because of their high damage potential in port cities.

Our paper makes advances in studying the determinants of container handling operations' durations, and thereby of emissions to air from ships during cargo handling and their associated external costs. A key contribution is its acknowledgement of the role that returns to density in handling operations – defined as the extended duration of loading/unloading operations[3] when an additional container is being handled, using the terminals' current infrastructures and facilities – play for ships' time and emissions in port: While previous studies on port emissions – including Tzannatos (2010), Berechman and Tseng (2012), and McArthur and Osland (2013) – have developed ship emission inventories and evaluated the external costs of emissions to air, we are unaware of other studies that relate in-port emissions to returns to density in handling operations. Moreover, little research has been devoted to external costs caused by feeders, which are the main concern of this paper. Feeders is the smallest category of container ships, and are mainly used in short-sea shipping and in draught-restricted ports (Stopford, 2009).

Our paper also makes advances in the study of determinants of ships' time spent in port by combining features of three strands of port studies: First, while previous *productivity and efficiency analyses* usually are based on annual (aggregate) data, we analyze each port of call to identify how the number of containers to be loaded/unloaded impact on the terminals' ship working rates; i.e., the ratio of containers handled to the duration of the cargo handling. This enables examining how well the terminals' current capacities are tailored to their demand, and to determine the marginal productivities of infrastructures and facilities. We are unaware of previous studies on this topic. Second, we map and operationalize relevant contextual variables based on insights from the *operations research* literature. Third, while our paper has similarities to previous *statistical analyses of ship turnaround times* and quay crane performances, it provides a richer description of potential determinants of the duration of cargo handling operations than past studies, ranging from terminal inputs, throughput volumes, and ships' capacities and capacity utilizations to contextual factors such as temperature, wind force, and daylight.

Having identified key determinants of the durations of cargo handling operations, we use emission factors based on the U.S. Environmental Protection Agency's (EPA, 2009) methodology to identify how emissions to air and their corresponding damage costs vary with the throughput volume and terminal characteristics. Consequently, our results provide guidance for port pricing, allowing the identification of Pigouvian tariffs on cargoes and service quality premiums.

This paper is structured as follows. The next section reviews the current literature on the time factor in ports' cargo handling. Section 3 presents our empirical production model while Section 4 provides a description of container port operations and identifies potential determinants of ship working productivities. Section 5 characterizes Norwegian container terminals and outlines the dataset, while Section 6 presents the empirical results. Section 7 concludes.

2. Literature review

This section briefly outlines how the time factor in cargo handling has been treated within three branches of the port literature, i.e., productivity and efficiency analysis, operations research, and statistical analysis of vessel port time.

2.1. Productivity and efficiency analysis

As noted by Ducruet et al. (2014), despite the diversity of approaches used to measure port productivity and efficiency, the time

[2] See *The Norwegian National Transport Plan* http://www.ntp.dep.no/Nasjonale + transportplaner/2018–2029/Godsprosjektet (Presentation, Summary and Freight Analysis are available in English).

[3] 'The duration of loading operations is the time between the start and finish of the ship working'.