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The energy efficiency effects of periodic ship hull cleaning

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ABSTRACT

This paper investigates the impact of periodic hull cleaning on oil tankers' energy efficiency using real 2012–2016 fleet performance and weather data extracted from noon reports for a fleet of eight identical Aframax-size crude oil tankers. The impact of changes in fuel consumption is estimated around the discontinuity when a vessel is cleaned and rely on both before-after and difference-in-differences estimators. The main results show that (i) periodic hull cleaning leads to a significant reduction in the daily fuel consumption; (ii) dry-docking leads to greater and significantly different reductions in fuel consumption than underwater hull cleaning, approximately −17% *versus* −9%; (iii) hull cleaning energy efficiency effect is greater when the vessel is sailing laden rather than in the ballast condition. These findings represent a key building block for the optimization of maintenance intervals.

1. Introduction

While ocean transport is considered to be the most energy-efficient transport mode in comparison to rail, road and air (IMO, 2009), the cumulative CO_2 emissions from international shipping are nevertheless substantial, estimated at about 2.2% of global emissions (IMO, 2015). This share is likely to increase due to growth in international trade and a slower rate of decarbonization than in land-based transportation (Energy Transitions Commission, 2017). Fuel is also a major cost driver in international shipping, accounting for 50–70% of a ship's total running costs (Rehmatulla and Smith, 2015). In aggregate, based on the estimated 201–272 million tonnes of fuel consumed annually for the 2007–2012 period (IMO, 2015), international shipping's fuel bill exceeds $80 billion per year.

The maritime industry has mostly focused on improving energy efficiency through technological and operational measures, and has a low uptake of alternative fuels and renewable energy sources (Rehmatulla et al., 2017). However, a large number of energy efficiency measures have been identified as being cost effective (IMO, 2009; Eide et al., 2011; Faber et al., 2011; Psaraftis and Kontovas, 2013).

Bouman et al. (2017) review several technologies for improving energy efficiency in shipping, such as using renewable energy sources (solar or wind propulsion), using fuel with lower carbon content (liquid natural gas or biofuel) or using emission reduction technologies (power and propulsion system). Their review of 150 studies concludes that it is possible to reduce GHG emissions by 50–60% per freight unit transported with current technologies within 2050. Rehmatulla et al. (2017) point out that only a few such measures are implemented by a large proportion of shipowners. Out of the 30 technologies for energy efficiency and CO2 reduction reviewed by the authors, the most common initiatives include bulbous bow designs, pre/post swirl devices to improve propeller efficiency, and the tuning, derating and waste-heat recovery of ship engines. A reason mentioned by Poulsen and Johnson (2016) is the lack of reliable data on energy efficiency measures or even sometimes a distrust on fuel consumption noon-reports. This lack of information represents a major barrier to energy efficiency, and this article contributes to lowering such a barrier to the implementation of operational measures.

The importance of operational measures was formalized with the adoption of the Ship Energy Efficiency Management Plan (SEEMP) by the International Maritime Organization (IMO) in 2011, mandating every ship owner to put in place a formal system to manage and optimize ship and fleet performance (Jensen et al., 2018). Key operational measures include general speed reduction,

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weather routing and periodical cleaning of the vessel's hull and propeller. Jensen et al. (2018) also emphasize how training in energy-efficient operation and awareness (using simulator training of crew) can improve energy efficiency. The study concludes that raising the awareness of the crew can save approximately 10% fuel, an effect particularly important for small shipping companies that may lack the resources to implement other energy efficiency solutions (Johnson et al., 2014; Poulsen and Johnson, 2016).

Using hull cleaning as a measure to curb emissions and improve the energy efficiency of the world fleet is also important for at least two reasons. First, hull fouling is a substantial contributor to increased emissions. For example, the third IMO greenhouse gas study (IMO, 2015) applies a fixed 9% yearly increase in fuel consumption across the world fleet to account for the resulting loss in energy efficiency. Second, it is the only main driver over which the ship owner has a large degree of control. Specifically, while the rate of marine growth on the hull (i.e. the ‘fouling’) is largely exogenous, the frequency and quality of periodic maintenance on the underwater hull (i.e. hull cleaning and propeller polishing) is decided by the ship owner.

In comparison, weather conditions are exogenous and exposure can only be minimized subject to an increase in journey time. General speed reduction as a measure of improving energy efficiency is important, but market-wide implementation has been hampered by the ‘split incentives problem’ as the savings (fuel costs) and costs (longer voyage) may be allocated to different agents as discussed in Rehmatulla and Smith (2015).

While it is clear that periodic hull cleaning can significantly improve the world fleet's energy efficiency, accurately measuring its impact is challenging due to the numerous other time-varying drivers of a vessel's fuel consumption, like speed, wind direction, wave height, rudder use and water temperature, to name only a few. In the literature, the impact of hull condition on fuel consumption is typically derived from ‘resistance modelling’ as developed in Todd (1967). This involves estimating a ship's total resistance and then removing or correcting for external factors such as wind, waves and other factors, leaving only the effects of hull and propeller fouling (Aas-Hansen, 2011).

This paper takes advantage of the improved availability of empirical fleet performance data and weather data to measure the energy-efficiency impact from two types of periodic hull maintenance: underwater cleaning and dry-docking. Compared to the theoretical model-based approach in the literature, the proposed measure is purely data-driven and implemented using two different estimators around the discontinuity when a vessel is cleaned (a ‘before-after’ estimator and a difference-in-differences estimator). The empirical analysis relies on data extracted from noon reports from January 2012 to December 2016 for a fleet of eight identical Aframax-size crude oil tankers.

The remainder of the paper is organized as follows. Section 2 reviews the literature on fuel consumption drivers and the impact of hull fouling and hull cleaning on fuel efficiency. Section 3 presents the vessel performance data set. Section 4 develops the econometric model to measure the effect from hull cleaning. Section 5 discusses the empirical results for our estimators and implements several robustness checks. Finally, Section 6 concludes.

2. Literature review

Due to the importance of ships' hull condition for both the environment and the economics of ship operation, it has attracted interest in a wide range of disciplines from naval architecture to biology and material science (antifouling paint technology).

In general, the empirical modelling of vessel performance is a technologically complex and expensive process that requires full-scale ship trials for a large dataset covering a multitude of ship and environmental conditions and this may take many years to accumulate. The theoretical foundation and analytical methods, as developed in Telfer (1926) and Todd (1967), are often termed ‘resistance modelling’ and involve estimating a ship's total resistance and then removing or correcting for external factors such as wind or waves, leaving only the effects of hull and propeller fouling (Aas-Hansen, 2011).

Resistance modelling has been criticized because it requires the estimation of several unknown friction-related coefficients. Pedersen and Larsen (2009) argue in favor of using artificial neural networks to predict propulsion power from the variables influencing ship resistance, such as ship speed, relative wind speed and direction, air temperature and sea water temperature. Sailing speed v is always considered as the principal determinant of a ship's resistance (Psaraftis and Kontovas, 2013; MAN Diesel and Turbo, 2004), but its influence changes (Meng et al., 2016) with the propeller and residual resistance that is mainly caused by waves and weather conditions (Lo and McCord, 1995). The influence of waves and wind is considered to be much more significant than that of ocean currents (MAN Diesel and Turbo, 2004; Carlton, 2012).

Generally, wind and waves coming towards the ship's bow and sides (beam wind or waves) will increase resistance and fuel consumption, while following wind or waves are beneficial. However, determining the precise quantitative influence of sailing and weather conditions on fuel efficiency is extremely complicated (Carlton, 2012). If wind and waves are generally the main reason for involuntary loss of speed (Herradón et al., 2016) and if waves usually constitute an important part of the vessel s total resistance (often 15%–30% of the ship's calm-water power), the added resistance in waves is the most difficult to predict. Bertram (2016) reviews approaches on added power in seaways and concludes that there is no practical approach to quantify the required added power in waves. It is worth noting that added resistance due to wind is important for certain types of ships with large windage areas (cruise ships, containerships and car carriers for instance).

A vessel's hull condition impacts energy efficiency due to the deterioration that occurs in hull and propeller performance over time, mainly as the result of biological fouling and mechanical damage (Kovanen, 2012). Even minor biofilms affect the hydrodynamics of a ship's hull by increasing drag and, therefore, the required propulsive power (Dennington, 2010). Fouling conditions can be exacerbated if the vessel has long idle periods or low activity such as frequent stays in port, and the rate of growth increases with sea temperature (Kovanen, 2012). The state of the underwater hull is most commonly assessed by visual inspection. However, fouling may not be uniform in coverage over the hull surface and heavy fouling may not be visibly seen from above-water inspection. Diving contractors are then hired for underwater hull condition inspection.

Hull fouling results in excess fuel use at a maintained speed or speed loss at a maintained engine power (Kane, 2012). As a secondary effect, hull fouling can also damage the structural integrity of the ship due to corrosion induced by the fouling. Regular hull cleaning and propeller polishing can assist in negating these effects. An additional environmental benefit of hull cleaning is the removal of potential invasive species (biofouling), the transfer of which is a major threat to the world's oceans and to the conservation of biodiversity. As current technologies for underwater hull cleaning focus on the removal of hull fouling and typically does not collect the biological waste, invasive species are only contained if the procedure is undertaken in dry-dock.

There are two different types of cleaning operations on a ship's hull. The quickest and cheapest is underwater hull cleaning, where