Transportation Research Part D 53 (2017) 37–49

Contents lists available at ScienceDirect

Transportation Research Part D

journal homepage: www.elsevier.com/locate/trd

The impact of regional environmental regulations on empirical vessel speeds

Roar Adland [a,*], Gro Fonnes [b], Haiying Jia [c], Ove D. Lampe [b], Siri P. Strandenes [a]

[a] Norwegian School of Economics (NHH), Helleveien 30, 5045 Bergen, Norway
[b] Christian Michelsen Research (CMR), P.O. Box 6031, 5892 Bergen, Norway
[c] Center for Applied Research at NHH (SNF), Helleveien 30, 5045 Bergen, Norway

ARTICLE INFO

Article history:
Available online 8 April 2017

Keywords:
AIS
Emission control areas
Vessel speed
Fuel prices
Green shipping

ABSTRACT

Economic theory suggests that the use of more expensive low-sulphur fuel within an Emission Control Area (ECA) should result in lower vessel speeds. The objective of this paper is to investigate empirically, for the first time, whether the introduction of an ECA affects vessel speeds. We utilize a dataset of observed vessel speeds derived from the Automated Information System (AIS) for nearly 7000 ECA boundary crossings over a three-year period. Our results suggest that introducing stricter sulphur regulations inside the North Sea ECA from 1. January 2015 did not affect vessel speeds once changes in macroeconomic conditions are accounted for.

1. Introduction

The International Convention for the Prevention of Pollution from ships (MARPOL), specifically Annex VI, sets limits on sulphur oxide (SOx) and nitrogen oxide (NOx) emissions from ship exhausts. In 2008 the International Maritime Organization (IMO) agreed on the latest version, stipulating that global limits on the sulphur content in marine fuels of 3.5% would be reduced to 0.50% in 2020 or 2025 subject to an interim review in 2018. MARPOL further defines four Emission Control Areas (ECAs) with even more stringent limits on sulphur content in marine fuels: the Baltic Sea, the North Sea and English Channel, the North American coast and the US Caribbean coast. The latter two areas also regulate NOx and particulate matter (PM) emissions. In the current paper we focus on the implementation of the North Sea ECA regulations, which from 22. November 2007 limited marine fuel sulphur content to 1.5%. A lower limit of 1% came into force 1st July 2010, declining further to 0.1% from January 1, 2015. From a technical point of view, there are three ways to comply with these regional MARPOL regulations. The simplest and most common approach is a modification of a vessel's fuel tank system to enable switching from the standard heavy fuel oil (HFO) consumed outside ECAs to marine gas oil when sailing within an ECA. Other alternatives include natural gas-powered propulsion (LNG) and the installation of exhaust cleaning systems for SOx (scrubbers). Much recent research has been devoted to choosing the optimal compliance strategy (see, for instance, Lindstad et al., 2015; Yang et al., 2012; Balland et al., 2012, 2013; Brynolf et al., 2014; Jiang et al., 2014; Schinas and Stefanakos, 2012). In these studies, the alternatives are commonly assessed according to a number of criteria such as investment and operating costs, reliability and maintenance requirements. It is typically recognised that the optimal solution is subject to uncertain future price differences of alternative fuels as well as technological and regulatory uncertainty. A common weakness is the focus on

* Corresponding author.
E-mail address: roar.adland@nhh.no (R. Adland).

http://dx.doi.org/10.1016/j.trd.2017.03.018
1361-9209/

cost minimization and failure to take into account that the inclusion of LNG propulsion or scrubbers will also affect a vessel's revenues. This is typically a result of a reduction in cargo-carrying capacity, either directly due to additional piping and larger fuel tank volumes, or indirectly by affecting a vessel's centre of gravity, for instance by placing heavy scrubber equipment high in the superstructure or LNG fuel tanks on deck for safety reasons. Moreover, as shown empirically in Adland and Strandenes (2007) for a perfectly competitive market, higher voyage costs merely increases the lower bound of the spot freight rate, passing increases in fuel prices on to the consumer of sea transport. From shipowners' point of view, this will favour compliance strategies that affect variable costs only (i.e. choosing fuel switching as opposed to additional investment in scrubbers or LNG retrofit). This important aspect is poorly understood in the literature on regulatory compliance.

A separate strand of the literature considers the impact that such environmental regulations should have on the operating patterns of vessels, notably as it pertains to speed choice and routing. The observation that the regulatory requirement to burn higher-priced low-sulphur fuel should influence speed stems from the classical research on speed optimization (see, e.g. Ronen, 1982). Because fuel consumption per time unit is approximately proportional to the cube of speed, it can be shown that the optimal (profit maximizing) speed in a one-period setting is approximately a function of the square root of the ratio between the freight rate and fuel price (Ronen, 1982). Accordingly, higher fuel prices, all else equal, should lead to reduced sailing speeds. Psaraftis and Kontovas (2013) provide a useful taxonomy and survey of the literature on speed models. Recent computational studies show, at least for the special case of liner shipping (Doudnikoff and Lacoste, 2014; Fagerholt et al., 2015) that a possible consequence of reduced sailing speeds within ECAs is that vessels must speed up outside to compensate for lost time, and that this will increase overall fuel consumption and CO_2 emissions. Fagerholt et al. (2015) also show that a likely effect of the regulations is that ship operators will choose to sail longer distances to avoid or reduce the sailing distances within the ECAs. Nevertheless, the main finding in the literature is that slow-steaming results in substantial reductions in carbon emissions (see, for instance, Corbett et al., 2009; Wang and Meng, 2012; Maloni et al., 2013; Zis et al., 2014; Ferrari et al., 2015).

We note that the literature on MARPOL compliance consists only of theoretical or computational studies, even though the North Sea ECA, for instance, has existed for nearly a decade. We seek to fill this gap in the literature by providing the first ever empirical study of vessel behaviour in regions affected by the ECA regulations. Specifically, the objective and contributions of this paper is to assess statistically (i) whether vessels slow down, on average, when entering an ECA and (ii) whether the introduction of the stricter ECA regulations on January 1st, 2015, affected speed patterns. We do this by building a unique and comprehensive dataset of high-frequency speed observations at the individual voyage level for ECA boundary crossings, derived from the international Automatic Identification System (AIS). The remainder of this paper is structured as follows: Section 2 describes the AIS data and our variable choices, Section 3 shows our empirical results and Section 4 concludes.

2. Data and variables

2.1. Introduction to AIS

Automatic Identification Systems are designed to automatically provide information about a ship and its location/course to other ships and coastal authorities, primarily with the goal of collision avoidance. Specifically, IMO regulation 19 of SOLAS Chapter V requires that AIS shall:

- Provide information – including the ship's identity, type, position, course, speed, draught, navigational status and other safety-related information – automatically to appropriately equipped shore stations, other ships and aircraft;
- Receive automatically such information from similarly fitted ships; monitor and track ships;
- Exchange data with shore-based facilities.

The regulation requires AIS to be fitted aboard all ships of 300 gross tonnage and upwards, engaged on international voyages, cargo ships of 500 gross tonnage and upwards not engaged on international voyages and all passenger ships irrespective of size. The requirement became effective for all ships by 31 December 2004 (IMO, 2015).

A good database of historical AIS data is a veritable treasure trove of high-frequency information on vessel behaviour. In principle, an accurate and complete dataset enables researchers to construct complete itineraries for any vessel or any fleet of vessels, with dynamic speeds and loading conditions, as well as detailed knowledge of the time spent in port, at anchorage or in repair yards. However, its application in academic research and commercial use has been hampered by the challenges in managing the extremely large volumes of data as well as varying quality and geographical coverage. As an illustration, the volume of raw data behind our study, as kindly provided by the Norwegian Coastal Authority (NCA) and collected since February 2nd 2005, is nearly 6000 Gigabytes of data.

2.2. Defining the sample

The data consists of large files with one line per AIS raw message, which are decoded, joined and inserted into a database. Obvious errors, e.g., messages not conforming to the standard or vessels seemingly moving in excess of 100 knots, are discarded. The data collected by NCA has a varying degree of spatial coverage as time progresses. From early 2005 the network expanded with terrestrial base stations, and in 2010 with the addition of satellite coverage. The terrestrial base-stations have