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EVALUATION OF THE INFLUENCE OF STRICTER SULPHUR LIMITS WITHIN EMISSION CONTROL AREA ON PORT STATE CONTROL INSPECTION

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ABSTRACT

This paper aims to identify if the regulation of stricter sulphur limits of 0.1% m/m within the emission control areas has an influence on the port state control inspection. Inspection records of 18 months before and after 1 January 2015 of 5 ports within and 5 ports outside the emission control areas are selected respectively as the sample data. The average deficiency number in a PSC inspection, average age of the inspected ships, ECA related deficiency rate and detention rate are selected as the inspection indicators. Three significant differences are found: (i) Ships calling the ports outside ECAs are of elder age than the ships calling the ports within ECAs; (ii) ECA related deficiency rate is higher in the ports within the ECAs while is lower outside ECAs; (iii) Ship detention rate in the ports outside ECAs is higher than that within the ECAs.

Keywords: emission control areas (ECAs), port state control (PSC) inspection, Mann-Whitney U test, Wilcoxon signed-rank test

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ABSTRACT

This paper aims to identify if the regulation of stricter sulphur limits of 0.1% m/m within the emission control areas has an influence on the port state control inspection. Inspection records of 18 months before and after 1 January 2015 of 5 ports within and 5 ports outside the emission control areas are selected respectively as the sample data. The average deficiency number in a PSC inspection, average age of the inspected ships, ECA related deficiency rate and detention rate are selected as the inspection indicators. Three significant differences are found: (i) Ships calling the ports outside ECAs are of elder age than the ships calling the ports within ECAs; (ii) ECA related deficiency rate is higher in the ports within the ECAs while is lower outside ECAs; (iii) Ship detention rate in the ports outside ECAs is higher than that within the ECAs.

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1. INTRODUCTION

Over the 50 years seaborne trade has seen a remarkable development. In 2017, 10.7 billion tons of global volumes were carried by sea (UNCTAD, 2018). Meanwhile, shipping operations produce large quantities of greenhouse gas (GHG) such as CO_2, and air pollutants such as nitrogen oxides (NO_x), sulphur oxides (SO_x), and particular matters (PM). Moreover, it is reported that SO_x emissions from shipping industry account for 10-15% of total global emissions (IMO, 2014). SO_x emissions can lead to acid rains and cause serious environmental as well as health problems, especially in the costal regimes (Corbett *et al.*, 2007; Xia *et al.*, 2019). However, much less attention has been payed to the environmental consequences of maritime transport emissions than other means of transportation due to the international nature of shipping industry and the fewer immediate perceptible impacts on the population (Cullinane and Bergquist, 2014). As SO_x emissions from ships are closely related to the consumption of bunker fuel, which is a waste product of the standard oil refining process and of low quality, an increasing number of international and local regulations have been focused on requiring ships to use cleaner fuel with lower sulphur content. For example, the International Maritime Organization (IMO) proposed the concept of “emission control areas (ECAs)” in which stricter controls are made to reduce sulphur emissions from ships since 2005. As of 2011, 4 ECAs had been established worldwide: the Baltic Sea ECA, the North Sea ECA, the North American ECA, and the US Caribbean ECA as required by MARPOL Annex VI. An illustration of the current ECAs is shown in Figure 1. Before 1 July 2010, no more than 1.50% m/m sulphur content fuel could be used within the ECAs. Since 1 July 2010, sulphur contained in ship fuel within the ECAs was required to be within 1.00% m/m while since 1 January 2015, the maximum allowed sulphur contained in ship fuel with ECAs was 0.10% m/m. Regarding the sulphur limits outside the ECAs, from 1 January 2012 to January 2020, the upper bound is 3.50% m/m, and after 1 January 2020, the upper bound will change to 0.50% (Cullinane and Bergquist, 2014).

Figure 1. An illustration of the current ECAs (Fagerholt *et al.*, 2015)

One of the important regimes to ensure the ships are in compliance with the sulphur limits regulations as well as other international maritime conventions is the port state control (PSC) inspection, which is an international regime to inspect the foreign coming ships. At present, there are nine Memorandum of Understandings (MoUs) on PSC all over the world to carry out PSC inspections, and the two main MoUs are Paris MoU and Tokyo MoU. During an inspection, the aspects that are not in compliance with the conventions are recorded as deficiencies, and if major (detainable) deficiencies are detected, the ship can be detained by the port state authority until it has rectified those deficiencies. After an inspection, the inspection results, which contain the identified deficiencies and ship detention, together with ship and other inspection information will be recorded in the corresponding database of the MoU. PSC MoUs pay much attention to inspecting the fuel quality and emissions of coming ships. It is reported by Paris MoU that in the past few years, equipment and compliance under MARPOL Annex VI has always been considered as inspection item for PSC inspection, such as SO_x records, ship fuel change-over procedure, quality of fuel oil, and sulphur content of fuel used (Paris MoU, 2017; Paris MoU, 2019).

The regulations of stricter sulphur limits within ECAs from 1 January 2015 has led to immediate and active responses in shipping industry. Several countermeasures have been come up with to reduce ship sulphur emissions in order to comply with the regulations. In addition, several studies have revealed that the establishment of ECAs can help to reduce SOx emissions and improve air quality (Brynolf *et al.*, 2014; Svindland, 2018; Chen *et al.*, 2018). However, the impacts of ECA related regulations on PSC inspection, which is regarded as the “second line of defense” and “last safety net” against substandard shipping have seldom been studies. To bridge this gap, this study evaluates the influence of stricter sulphur limits within the ECAs on PSC inspection based on the inspection records of 5 ports within the ECAs and 5 port outside the ECAs from the database of Paris MoU.

2. LITERATURE REIVEW

2.1 Research on ECAs’ effects

The current and upcoming stricter sulphur limits within the ECAs lead to the development of various technical and operational solutions to comply with these regulations. The technical measures refer to the use of higher quality fuel and installation of the equipment/systems that can reduce SO_x emissions. There are three main technical measures that are widely adopted in shipping industry: using liquefied natural gas (LNG), installing the exhaust emission scrubber devices to filter sulphur, and use fuel with lower sulphur content, such as marine gas oil (Brynolf *et al.*, 2014; Panasiuk and Turkina, 2015; Lindstad *et al.*, 2017; Kim and Seo, 2019). A considerable amount of literature has analyzed the pros and cons of the three measures and made comparisons among them. Brynolf *et al.* (2014) found that all the three commonly used alternatives could reduce the emissions of air pollutants from ships. Jiang *et al.* (2014) further compared the installation of sulphur scrubber and using marine gas oil. The conclusion was that marine gas oil had higher net percent values when the price was less than 231

Euros per ton, while the new ships were more suitable to install a scrubber. Panasiuk and Turkina (2015) developed a cash flow model to compare the strategies of using low sulphur fuel and installing scrubber from an economic perspective. They pointed out that the investments in scrubber installation could be viewed as more effective than using low sulphur fuel under any fuel price. Lindstad *et al.* (2017) also made comparisons among the different alternatives. They concluded that installing on-board exhaust scrubbing to wash heavy fuel oil (HFO) would yield the lowest cost for larger vessels while diesel was a good option for smaller vessels. The factors influencing the shipping companies' choices among the strategies are also analyzed. For example, Kim and Seo (2019) found that investment costs were the dominant influencing factor, followed by operating costs, government/port support, and fuel consumption costs by conducting surveys and interviews.

There are also studies on developing operational solutions, which mainly refer to finer planning ship speed, sailing routes, and schedule within and outside the ECAs. Fagerholt *et al.* (2015) developed a sailing speed and path optimization model for a ship along a given sequence of ports to minimize the fuel costs. They also found that the side-effects of stricter sulphur content regulations were that the ship operators would often choose to sail longer distance to reduce sailing time within ECAs and they would sail at lower speed within ECAs while higher speed outside ECAs. Dulebenets *et al.* (2017) proposed a mathematical model to re-schedule a vessel by imposing constraints on the emissions of the vessel on each voyage leg of a liner shipping route. They demonstrated the changes in vessel schedule when emission control policies were imposed. Chen *et al.* (2017) also reported that the establishment of ECAs would results in a considerable portion of ships to re-route around the ECAs, especially for the smaller ships. Zhen *et al.* (2018) proposed a mixed integer programming model to re-schedule voyage plans by optimizing speeds, sailing patterns, and ports-of-call sequences within and outside the ECAs in order to reduce fuel costs.

2.2 Research on factors influencing PSC inspection

According to a review on PSC inspection, both ship related factors and non-ship related factors will influence the PSC inspection results (Yan and Wang, 2019). With regard to ship-related factors, Cariou *et al.*, (2007) concluded that the three dominant factors influencing the deficiency number identified in PSC inspections were ship age, ship flag, and ship type. They further pointed out that the weighting points that should be assigned to ship age, ship recognized organization, and inspecting place were 40%, 31%, and 17%, respectively regarding detention possibilities in PSC inspections (Cariou *et al.*, 2009). Factors influencing ship detention and leading to high number of deficiencies were also analyzed. Cariou and Wolff (2015) reported that similar factors would influence the likelihood of ship detention and identifying high number of deficiencies by adopting quantile regression. They also listed the vessel types that resulted in high deficiency number and possibility of detention respectively.

With respect to non-ship factors, the area of where a PSC inspection takes place and the background of the port state control officers (PSCOs) can have impact on PSC inspection results. Knapp and Franses (2007) concluded that there were many differences existing among the PSC regimes, especially the detainable deficiencies, even if the basic ship profiles, such as ship age, size, flag, class and ownership did not vary significantly across the regimes. Knapp and van de Veldon (2009) also pointed out that although some strong associations of regimes existing in certain deficiency areas, the treatment of vessels across the PSC regimes differed a lot. Discrepancies in PSC inspections can exist even in the same MoU. Ravira and Piniella (2016) evaluated the influence of professional profile of PSCOs on inspection results within Paris MoU. Graziano *et al.* (2017) pointed out that differences in maritime knowledge and structure of the inspection process would lead to difference in PSC inspection between Northern and Southern EU countries. Graziano *et al.* (2018) further analyzed the discrepancies among the member states of the Paris MoU and the influence of PSC team composition and inspector's background on PSC inspection outcome.

Although there is a large amount of research on the effects of the establishment and stricter sulphur limits within ECAs as well as the influencing factors of PSC inspection, to the best of our knowledge, there is no study discussing whether the stricter regulations in ECAs have impacts on the PSC inspection. To bridge this gap, this study aims to analyze if the stricter sulphur limits of 0.1% m/m within ECAs since 2015 have an influence on the PSC inspection, including the inspected ships and the inspection results.

3. DESCRIPTION OF DATA AND COMPARISON METHODS

To figure out if the implementation of stricter sulphur limits within the ECAs have impact on PSC inspection, two time periods are selected before and after 1 January 2015: Period i: July 2013 to December 2014 (18 months) and Period ii: January 2015 to June 2016 (18 months). 5 main ports within the ECAs and 5 main ports outside the ECAs are selected as the representatives, respectively. The 5 selected ports within ECAs are the Port of Antwerp (Belgium), the Port of Rotterdam (Netherlands), the Port of Bremerhaven (Germany), the Port of Felixstowe (United Kingdom), and the port of Hamburg (Germany). The 5 selected ports outside ECAs are the port of Algeciras (Spain), the Port of Barcelona (Spain), the Port of Valencia (Spain), the Port of Marsaxlokk (Malta), and the port of Piraeus (Greece). The PSC inspection records of the 10 ports during the two time periods are downloaded from PSC database of Paris MoU (https://www.parismou.org/inspection-search/inspection-search). Four comparison indicators are selected: average deficiency number in a PSC inspection (denoted by "def_NO"), average age of the inspected ships (denoted by "avg_age"), ECA related deficiency rate (denoted by "ECA_def_rate", calculated by dividing the total number of ECA related deficiencies by total number of inspections), and detention rate (demoted by "det_rate ", calculated by dividing the total number of detentions by total number of inspections). Note that the data is on a month basis and is the sum/average of all the selected ports within/outside the ECAs. Based on the comparison indicators, four comparisons are conducted:
C1: Comparison between the ports within and outside the ECAs in Period i;
C2: Comparison between the ports within and outside the ECAs in Period ii;
C3: Comparisons between Period i and ii regarding the ports within ECAs;
C4: Comparisons between Period i and ii regarding the ports outside ECAs.

In C1 and C2, the samples are dependent (matched) as they both come from the same ports and the values are continuous. As the samples cannot be assumed to be normally distributed, we adopt Wilcoxon signed-rank test to determine whether the two dependent samples are selected from populations having the same distribution. Wilcoxon signed-rank test was proposed by Frank Wilcoxon and it is a non-parametric statistical hypothesis test used for comparing dependent data (Wilcoxon, 1954). It can be regarded as an alternative of *t*-test for matched pairs (Lehmann and Romano, 2006). In C3 and C4, the samples are independent as they both come from different ports. Also, the samples cannot be assumed to be normally distributed. Thus, we select Mann-Whitney U test to determine whether the two independent samples are selected from populations of the same distribution. Mann-Whitney U test was proposed by Henry Mann and Donald Ransom Whitney (Mann and Whitney, 1947). It is a non-parametric test and can be regarded as an alternative of *t*-test for independent pairs (Lehmann and Romano, 2006). The null hypothesis of both the tests is that the two samples are selected from the populations of the same distribution. The confidence level is set to be 95% and the significance level α is set to be 0.05, i.e., if $p > \alpha$, the null hypothesis is accepted; if $p < \alpha$, the null hypothesis is rejected.

4. COMPARISON RESULTS AND ANALYSIS

The p-values of the four comparisons are shown in Table 1.

Table 1. *p*-values of the four comparisons

Comparison	def_NO	avg_age	ECA_def_rate	det_rate
C1	0.815	0.000	0.000	0.010
C2	0.029	0.009	0.000	0.011
C3	0.887	0.081	0.740	0.924
C4	0.094	0.267	0.198	0.500

Table 1 indicates that most of the comparison indicators in C1 and C2, i.e., def_NO, ave_age, ECA_def_rate, and det_rate are with $p < \alpha$, except for indicator def_NO in C1. In other words, we should reject the null hypothesis and accept the alternative hypothesis for the indicators with $p < \alpha$: the samples within and outside the ECAs in both Period i and Period ii are not from the populations of the same distribution. To put it another way, the differences in these indicators between C1 and C2 are statistically significant. Meanwhile, for comparisons C3 and C4, all the comparison indicators are with $p > \alpha$. Thus, we should accept the null hypothesis that for ports within and outside the ECAs in both periods respectively, the samples are from the populations of the same distribution, i.e., the differences between Period i and Period ii are not statistically significant. This may be because since January 2010, a 0.1% maximum sulphur requirement for ship fuels at berth in EU ports has already been introduced. The maximum fuel sulphur requirement is the same as that can be used within the ECAs since 2015.

To make more specific comparisons in C1 and C2, we further compare the differences in their medians, and the results are presented in Table 2.

Table 2. Medians of the significant indicators in C1 and C2

Comparison	outside/ within the ECAs	period	def_NO	avg_age	ECA_def_rate	det_rate
C1	within	i	\	9.7200	**0.0596**	0.0195
	outside	i	\	**11.8550**	0.0148	**0.0381**
C2	within	ii	**2.3750**	10.3000	**0.0633**	0.0183
	outside	ii	2.0100	**12.1300**	0.0140	**0.0363**

For each indicator, the larger value is in bold. It can be seen from Table 2 that in both C1 and C2, the average age of the inspected ships is higher in the ports outside ECAs. This reveals that the newer ships are more likely to comply with sulphur limits. In addition, much more deficiencies related to ECA are detected at the ports within the ECAs. The implications are in twofold: first, this implies that while most of the ships can comply with the sulphur limits outside ECAs, they cannot meet with the stricter sulphur emission regulations within ECAs; second, as not all of the deficiency items will be inspected in one PSC inspection, much more ECA related deficiencies detected within the ECAs may also because the port states within the ECAs pay more attention to inspecting ECA related deficiencies than the ports outside ECAs. Although the ships are with higher ECA related deficiency rate in ports within the ECAs and the average deficiency number is higher in ports within ECAs than in ports outside the ECAs in period ii, the detention rate at ports outside ECAs is much higher. As the inspection regulations are the same in one MOU, it can be concluded that the ships inspected outside the ECAs are in much worse conditions than the ships inspected within ECAs.

5. CONCLUSIONS

The past few years have witnessed an increasing number of international environmental regulations on emissions from shipping. Especially, the current and upcoming stricter sulphur limits within the ECAs have drawn wide attention from shipping industry. Various countermeasures are proposed and implemented for the ships to comply with the increasingly stricter regulations. Nevertheless, there is rare research on analysis of the influence of stricter ECA regulations on PSC inspection, which is an important international regime to guarantee the ships are in compliance with the international regulations. In this study, we select PSC inspection records of 5 ports within the ECAs and 5 ports outside the ECAs in two time periods: 18 months before 1 January 2015 and 18 months after 1 January 2015 to identify if there is significant influence of stringent ECA related regulations on PSC inspection. More specifically, four comparisons are conducted: C1, comparisons between the ports within and outside ECAs in Period i; C2: comparisons between the ports within and outside ECAs in Period ii; C3:

comparisons between Period i and ii of the ports within ECAs; C4: comparisons between Period i and ii of the ports outside ECAs. Four comparison indicators are chosen: the average deficiency number in a PSC inspection, average age of the inspected ships, ECA related deficiency rate and detention rate.

The statistic results are as follows: (a) The Mann-Whitney U test shows that the differences in medians of all the indicators in C1 and C2, except for the average deficiency number in C1, are statistically significant, i.e., all the p-values are smaller than 0.05. (b) The Wilcoxon signed-rank test shows that the differences in medians of all the indicators in C3 and C4 are not statistically significant, i.e., all the p-values are larger than 0.05. This may be because since January 2010, a 0.1% maximum sulphur requirement for ship fuels at berth in EU ports has been introduced. The findings are as follows: (a) For the ports within and outside ECA respectively, stricter sulphur limits since 2015 have little influence on the average deficiencies of an inspection and the age of the inspected ships, ECA related deficiency rate and detention rate in PSC inspection. (b) The ships calling the ports outside ECA are of elder age than the ships calling the ports within ECAs in both periods. This reveals that the newer ships may better comply with the sulphur limits regulations. (c) ECA related deficiency rate is higher in the ports within the ECAs while is lower outside ECAs in both periods. This indicates that although some of the ships are able to obey the sulphur content regulations outside ECAs (3.50%), they cannot meet the fuel requirements within the ECAs (0.10%). (d) Ship detention rate in the ports outside ECAs is higher than that within the ECAs in both periods. This implies that the ships calling the ports outside the ECAs are more likely to have detainable deficiencies, i.e., these ships are in worse and higher-risk conditions. From the perspective of new policy and management, accurate prediction models, which incorporate ship related factors and are based on machine learning and data mining technics should be developed to identify the risk level of the visiting ships. In addition, PSC authorities outside the ECAs should select the inspecting ships more carefully while PSC authorities within the ECAs should pay more attention to the elder ships.

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