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Research article

Costs and benefits of low-sulphur fuel standard for Baltic Sea shipping

Jim Antturi [a, 1], Otto Hänninen [b], Jukka-Pekka Jalkanen [c], Lasse Johansson [c], Marje Prank [d], Mikhail Sofiev [d], Markku Ollikainen [a, *]

[a] University of Helsinki, Department of Economics and Management, Latokartanonkaari 7, P.O. Box 27, FI-00014, Finland
[b] National Institute for Health and Welfare, THL Health Protection, P.O. Box 95, FI-70701 Kuopio, Finland
[c] Finnish Meteorological Institute, Erik Palmenin aukio 1, P.O. Box 503, FI-00101 Helsinki, Finland
[d] Finnish Meteorological Institute, Erik Palmenin aukio 1, 00560, Helsinki, Finland

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ABSTRACT

The maximum allowable fuel sulphur content for shipping in the Baltic Sea dropped from 1%S to 0.1%S in 1 January 2015. We provide a cost-benefit analysis of the sulphur reduction policy in the Baltic Sea Sulphur Emission Control Area (SECA). We calculated the abatement costs based on shipowners' optimal decision-making in choosing between low-sulphur fuel and a sulphur scrubber, and the benefits were modelled through a high-resolution impact pathway analysis, which took into account the formation and dispersion of the emissions, and considered the positive health impacts resulting from lowered ambient $PM_{2.5}$ concentrations. Our basic result indicates that for the Baltic Sea only, the latest sulphur regulation is not cost-effective. The expected annual cost is roughly €465 M and benefit 2200 saved Disability Adjusted Life-Years (DALYs) or monetized €105 M. Based on our sensitivity analysis, the benefits yet have a potential to exceed the costs. The analysis neither takes into account the acidifying impact of sulphur nor the impact North Sea shipping has on the cost-benefit ratio. Lastly, a similar approach is found highly recommendable to study the implications of the upcoming Tier III NO_x standard for shipping.

1. Introduction

International shipping is a significant source of air pollutants such as NO_x, SO_x and PM (particulate matter) and poses negative health externalities (e.g. Corbett et al., 2007; Brandt et al. 2013; Jonson et al., 2015). This has been recognized and the International Maritime Organization (IMO) has tackled air pollution resulting from shipping in Annex VI of MARPOL 73/78, in which SO_x is regulated through limits for fuel sulphur content and NO_x via emission standards for new engines. For NO_x, Tier I-II standards for engines are already in effect globally, whereas currently the Tier III standard is in effect only in the North American Emission Control Area. The IMO mandated the reduction of global maximum fuel sulphur content from 4.5%S to 3.5%S in 2012 and further to 0.5%S in 2020 (or alternatively in 2025). The regulation primarily concerns sulphur content in fuels and secondarily sulphur emissions, of which over 95% is SO_2 (Petzold et al., 2010). The current paper concentrates on analysis of these sulphur-emission reduction measures. Previous analysis (e.g. Bosch et al., 2009; Jonson et al., 2015; Schembari et al., 2012) has shown that reductions in fuel sulphur contents have positive impacts at a local scale on air quality and health. These findings have been corroborated in many studies elsewhere (see e.g. Contini et al., 2015; Viana et al., 2015 and Broome et al., 2016).

In the EU, MARPOL sulphur regulations were first implemented in the Sulphur Directive (1999/32/EC) and in the current form in an amending directive (2012/33/EU). As described in Annex VI, particularly vulnerable areas can be declared Sulphur Emission Control Areas (SECAs). In Europe, the Baltic Sea, the English Channel and the North Sea were declared SECAs in an amending directive (2005/33/EC). In SECAs the limit for fuel sulphur content has been and is stricter: 1.5%S between 6/2006–6/2010, 1.0%S during 7/2010–12/2014 and 0.1%S as of 1/2015.

After revising the directive in 2005, the European Commission authorized a cost-benefit analysis to study the impacts of SECAs. The study by Bosch et al. (2009) indicates positive net benefits for Europe. In 2015, assuming that the current SECA regulations apply,

* Corresponding author.
E-mail address: markku.ollikainen@helsinki.fi (M. Ollikainen).
[1] Present address: Finnish Forest Industries Federation, Snellmaninkatu 13, P.O. Box 336, FI-00171 Helsinki, Finland.

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the yearly health benefits are estimated to be €8–16 billion and abatement costs €0.6–3.7 billion.[2] For the Baltic Sea states alone, the resulting health benefits[3] are up to €5 billion but without Germany and Poland only €262 million. The corresponding cost for the Baltic Sea transport is in the range of €168–901 million.

The range of shipping's impact on human health has been assessed in subsequent studies but the results vary. On one hand, Brandt et al. (2013) estimate that SO_x and NO_x emissions from shipping in the European SECAs (the Baltic Sea and North Sea) caused chronic mortality measured as 149 000 years of life lost (YOLLs) annually. The study has a Europe-wide perspective and the impact is based on 2011 shipping with 1.0%S regulation. Jonson et al. (2015), on the other hand, estimate that shipping in the same area caused cumulatively circa 2 785 000 YOLLs (or roughly 55 700 YOLLs annually if assumed that the impact can be annualized by dividing the accumulated number by 50) in 2011. The adverse health impact in the study are mostly caused by SO_x and are also based on 1.0%S regulation in the SECAs. The impact covers the European countries in close proximity to the SECAs. The differences between the two studies can be explained, according to Jonson et al. (2015), by the dissimilarity of the regions covered by the modelling, uncertainties with calculated ambient $PM_{2.5}$ concentrations, difference with the resolution, and other methodological choices.

The distribution of the costs and benefits of SECAs has raised discussion. Geographically isolated countries at the end of the Baltic Sea, which are small in population, claim to be the net payers of the latest 0.1%S regulation. To our knowledge, the particular cost-benefit ratio of lowering fuel sulphur content from 1.0%S to 0.1%S is unknown for individual Baltic Sea states.

Given the scarcity of available analyses, we conduct a cost-benefit analysis of the latest SECA regulation. We apply state-of-the-art methods to derive the health benefits and abatement costs associated with the latest SECA standards for the Baltic Sea states. The benefits are defined through an impact pathway analysis (see e.g. Rabl et al., 2014). The highly accurate location of the emissions resulting from each individual ship, as well as the emissions' dispersion and transformation in the atmosphere is modelled with high-resolution models. Estimates of the health impacts are based on high-resolution population data and exposure-response functions (ERFs) for selected health indicators. Finally, the health benefits are expressed in monetary terms based on the Value of a Life Year (VOLY) concept.

To assess the corresponding costs for the ships sailing in the Baltic Sea, we estimate the number of ships that have chosen to switch to 0.1%S fuel, as well as the number of ships that have installed a sulphur scrubber to comply with the Sulphur Directive. To simulate the decision faced by shipowners, we conduct a present value comparison individually for each ship in order to give the best estimate of the abatement method chosen and the cost attributed to it. Furthermore, an additional, refined impact analysis is presented from Finland's point of view to illustrate the effect on an individual country's industrial competitiveness.

Our analysis differs from previous studies in two significant ways. Firstly, we utilize higher resolution for the health impact modelling to accurately extract the benefits. Secondly, our model simulates shipowners' decision making by applying present value comparison between choosing low-sulphur fuel or a sulphur scrubber. Wide adoption of LNG was not considered in the current study, because in 2015 only limited LNG bunkering infrastructure exists. However, LNG option may be important for new vessels because it is expected that currently ongoing LNG infrastructure projects will be completed in the next 5–10 years.

In the following section we describe the theoretical framework for our cost-benefit analysis, and then display the material used in the study. The output of our analysis is presented in the results section, followed by a sensitivity analysis. In the concluding section we summarize the main findings of the paper.

2. Cost-benefit framework

The net benefit (NB) of the EU Sulphur Directive is defined as the difference between the benefits (B) and costs (C).

$$NB = B - C \tag{1}$$

Due to the *in medias res* nature of the policy (Boardman et al., 2014), both costs and benefits are estimates of the expected future impacts expressed in monetary terms. Costs and benefits occurring in the future are discounted in order to assess the policy's impacts in present value. The following sections describe the framework in more detail.

2.1. Particulate matter: an impact pathway analysis

When the coastal states in Europe agreed to establish SECAs, the ambient-acidifying qualities of SO_x and the health impacts attributed to PM were a major concern. We take into account the health benefits linked to reduced $PM_{2.5}$ concentrations only. As a single stressor $PM_{2.5}$ is the dominating cause for environmental burden of disease (EBD) in Europe (Hänninen et al., 2014). Plausibly the burden of disease of $PM_{2.5}$ covers the greatest component of the benefits. Thus, we calculate potentially the lower-end estimate for the benefits because environmental benefits are not evaluated.

Not only is it important to acknowledge that ships are emitting $PM_{2.5}$ but also to realize that the vessels are constantly moving. Additionally, $PM_{2.5}$ travels long distances in the atmosphere and secondary aerosol formation from gases to PM contributes to elevated inland PM concentrations as well. According to an overview by Viana et al. (2014) prior to the 2015 SECA regulation, shipping's contribution to $PM_{2.5}$ in European coastal areas has typically been some 1–14%, but in most cases closer to the lower end of the scale.

Human exposure to $PM_{2.5}$ is tightly linked to deaths, diseases and disorders related to various lung and cardiovascular conditions (Pope and Dockery, 2006). As expressed in the Clean Air For Europe (CAFE) project, $PM_{2.5}$ is strongly linked with the incidence of cardiopulmonary disease (CP), lung cancer (LC), chronic obstructive pulmonary disease (COPD) and restricted activity days (RAD). According to Hänninen et al. (2014), some of the overlapping effects of other symptoms can be avoided by choosing to take into account the aforementioned symptoms.

Exposure-response functions (ERFs) for the selected health endpoints ultimately define the health impact as a function of exposure to $PM_{2.5}$. We assume linear ERFs without threshold. Therefore, the health benefits of the Sulphur Directive over eight Baltic Sea riparian countries (*e*) are equal to the impact it has on the EBD associated to $PM_{2.5}$. Russia was excluded from the analysis due to a lack of data. The impact is the real value of the difference between the EBD in the two scenarios we have created, the *Sulphur Directive Scenario* (^{1}) and the *Baseline Scenario* (^{0}), multiplied by VOLY.

[2] All monetary values in Bosch et al. are expressed in 2005 prices. The analysis is based on the impacts attributed to the 0.1%S EU port regulation and the lowering of the SECA standard from 1.5%S to 0.1%S.

[3] Bosch et al. report only the upper bound value for benefits in the Baltic Sea region, but the lower bound is expected to be half of the one reported. The benefits do not take Russia into account.