
The innovation inducement impact of environmental regulations on maritime transport: a literature review

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Abstract: Maritime transport is facing wide-ranging challenges due to stricter environmental regulations. It has been positioned that these stricter environmental regulations will significantly hamper the competitiveness of the shipping industry and other export/import oriented industries. However, contrasting views, arguing that environmental regulations will, in fact, enhance firms' competitiveness by inducing innovation, have also been voiced. Here, this issue is examined through a literature review on the innovation inducement impact of environmental regulations (i.e., the Porter Hypothesis), in general, and the economic impacts of environmental regulations (here Annex VI of the MARPOL Convention) as it applies to shipping in Northern Europe, in particular. According to the review, the literature is still inconclusive and lacks a clear consensus on the economic and innovation inducement impacts of environmental regulations on maritime transport. Therefore, the review concludes in suggestions for further studies on the use of marine scrubber systems as an illustrative case study example.

Keywords: environmental regulations; innovation inducement; marine scrubber systems; maritime industry; maritime transport; Northern Europe; Porter Hypothesis; shipping.

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1 Introduction

“Necessity is the mother of invention.” Plato

Shipping is globally the most important way of transport: ~90% of goods are transported by ships ([Nikolakaki, 2013](#)). For long, the volume of sea transport has shown an increasing trend (UNCTAD, 2008), despite temporal slowdowns due to economic crises. The traffic volume has been growing also in the Baltic Sea ([Inkinen and Tapaninen, 2009](#)). Maritime transport has traditionally been considered as an environmentally friendly and energy efficient mode of transport (Kontovas and Psaraftis, 2011a). However, we have to bear in mind that maritime transport releases a multitude of emissions: chemical, physical and biological. Moreover, whereas other modes of transport have been improving their environmental performance, shipping is lagging behind. Therefore, compared with the other modes of transport the share of negative environmental effects from shipping has been increasing ([Nikolakaki, 2013](#)). Therefore, maritime transport is facing extensive changes in the future, and the forthcoming environmental regulations are key factors in facilitating this change ([Makkonen et al., 2013](#)).

The impacts (costs and benefits) of environmental regulations for individual firms and industries have been widely discussed and estimated ([Rennings and Rammer, 2011](#); [Cainelli et al., 2013](#)). At the same time, terms such as corporate environmental (and social) responsibility have been incorporated in the managerial literature to discuss ethically and environmentally sound performance at the firm level (Dummet, 2006; [Yliskylä-Peuralahti and Gritsenko, 2014](#)). In short, environmental regulations are expected to lead to health and environmental benefits and induce a need for finding new ways of doing things. Therefore, environmental regulations are likely to boost the need for higher research and development (R&D) allocation for new environmentally friendly products, services, processes, working methods or techniques, i.e. environmental innovations (or eco-innovations). However, this is not always the case, since firms may, for example, lack the resources needed to invest on innovation (European Commission, 2013). In line, policy guidance in turning environmental regulations into a winning strategy for the individual firms is still missing. Therefore, there is a need for better understanding on how environmental regulations affect the innovation behaviour of individual firms. Thus, following the influential paper by [Porter \(1991\)](#), this paper addresses the issue of how environmental regulations might be turned into a competitive strength and advantage (sometimes referred to as green or in the case of shipping blue growth) by reviewing:

- the feasibility of the so-called Porter Hypothesis
- the economic, environmental and health impacts of the environmental regulations by the International Maritime Organization's (IMO) Annex VI of the MARPOL Convention, that set limits for sulphur (and nitrogen) content in marine fuel in the Northern European SECA, i.e., Sulphur Emission Control Area (there are also other designated areas, including North American and Caribbean SECAs, but here the focus is specifically set for the case of the Northern European SECA)
- the issue of innovation inducement impact of these regulations with the case of marine scrubber systems (developed for cleaner shipping, they reduce the amount of impurities in ships' fuel emissions).

The question addressed, is whether the environmental regulations imposed by IMO could lead to a favourable innovation inducement impact and thus carry with it economic benefits to the individual firms in the maritime industry and on a broader level to the countries surrounding the designated SECAs.

For achieving the sulphur limits set in the IMO Annex VI of the MARPOL Convention, commonly discussed solutions include the switch to low-sulphur marine fuel (LSF), slow steaming and the use of marine scrubber systems. Of these, the marine scrubber systems represent the clearest case of a technological innovation. Therefore, marine scrubber systems are used here as an example of the innovation inducement impact of environmental regulations. The reviewed literature (covering a time period of 1991–2013) was gathered through word searches ('Porter Hypothesis', 'marine scrubber', 'MARPOL' and 'SECA') in the Google Scholar. Google Scholar was used (instead of, for example, Web of Science or Scopus databases) to allow also the identification of 'grey' literature (policy papers and publications by research organisations) important for the topics at hand. However, it has to be noted that the reviewed literature here does not cover the entire range of the research done on the discussed topics (rather, it has to be treated as a representative sample), due to the sheer volume of literature discussing the Porter Hypothesis and the difficulties in identifying relevant 'grey' literature. Thus, an appraisal of all the research done on the subjects under review here remains out of the scope of this study.

Although earlier studies have reviewed the literature revolving around the Porter Hypothesis (Ambec and Barla, 2006; Iraldo et al., 2011; Ambec et al., 2013) and an example with a (somewhat) similar approach can be found in the case of the economic, environmental and health impacts of IMO regulations (European Commission, 2011), these issues have in the past been discussed separately. Moreover, concrete examples (such as the marine scrubber systems) have been rarely reviewed when debating the accuracy of the statements concerning the innovation inducement impact of environmental regulations. Here also lies the novelty of this paper's approach to combine these varying strands of research. The aim here is to produce relevant suggestions for further empirical studies and regulation procedures. Thus, we intend to scrutinise the dialogue between the industry and legislative-regulatory sides of the debate in order to alleviate the distinct dichotomy (economy–environment), which exists between these differing strands of thought. Environmental regulations need not always be considered as a negative factor on productivity at the firm level. Then again, environmentalists

should not consider firms as fundamentally immoral, i.e., environmentally unconscious. The resistance towards environmental regulations is more due to the fact that in many cases the costs and benefits are imposed on different industries and on different geographical areas: some face the costs while others enjoy the benefits. For example, firms may only be against the strict timelines imposed, geographical delineations to be affected or the method of implementation and, in fact, may choose to be green even without environmental regulations (Lambertini and Tampieri, 2012). Opening up these lock-in conceptions is vital for a successful innovative and environmental future. Therefore, there should be more discussion on how to better induce environmental innovations with policy instruments (Veugelers, 2012). This should be viewed in a broad scale including not only the policy document itself, but also the importance of dialogue, guidance and briefing in facilitating the acceptance of environmental regulations.

The chosen approach here is highly policy relevant as both of the main themes, innovation and the environment, addressed here are among the flagship initiatives ('Innovation Union' and 'Resource efficient Europe') of the European Union to achieve the goals of 'Europe 2020' (European Commission, 2010). Moreover, this review will directly address the themes of the HELCOM (2007) 'Baltic Sea Action Plan' through examining the possibilities to develop the region 'towards a Baltic Sea with maritime activities carried out in an environmentally friendly way'. The remainder of this paper is structured as follows:

- the Porter Hypothesis is introduced together with an overview on the relevant empirical works testing the accuracy of it
- the IMO regulations for prevention of air pollution (sulphur in particular) from ships are outlined together with a summary on the selected literature presenting empirical estimations on the economic, environmental and health impacts of these regulations in the Northern European SECA and surrounding countries
- as a special case of a technological innovation induced by the regulations, notions on the technical aspects of marine scrubber systems are presented together with the existing literature on their economic benefits and drawbacks.

Discussion on the implications of the reviewed literature and suggestions for further research will conclude the paper.

2 Environmental regulations and innovation inducement: the Porter Hypothesis revisited

In the literature on environmental economics, commonly, three implements for environmental regulations—which as opposed to guidelines are enforced as mandatory, while compliance to guidelines is voluntary (Mancini et al., 2006) are distinguished:

- emission limits and standards
- taxes
- certificates (Wagner, 2003).

Moreover, the regulatory standards can be further considered as best-available-technology or performance measures ([Huber, 2008](#)). According to [Johnstone \(2005\)](#) the performance-based measures will provide strong, whereas the technology-based measures will provide little, incentive for innovation and diffusion of technologies to achieve given environmental standards. Similarly, the innovation inducement methods can be categorised into two groups:

- demand-pull
- technology-push policies ([Nemet, 2009](#)).

Demand-pull policies are targeted at raising the payoff for successful innovations through activities such as regulatory standards and taxes on competing technologies, whereas technology-push policies are measures targeted at reducing the costs of producing innovations through, for example, tax credits and direct funding for R&D.

The conventional wisdom in economics and managerial sciences has been that environmental regulation imposes heavy costs, slows growth and therefore hinders national and organisational competitiveness. The recognition of this resistance to assent to the notion that well-designed environmental regulations might lead to improved competitiveness acted as a catalyst for Michael Porter to speak up for the environment—however, actually [Ashford et al. \(1985\)](#) had come to quite a similar conclusion well before Porter. Since Porter's (1991) statement, which has been aptly named as the Porter Hypothesis, of the effects of environmental legislation and regulations on the competitive strength of firms and nations, the issue has frequently been brought to the fore of economic debate. Porter himself together with [Claas van der Linde \(1995, p.98\)](#) redefined his hypothesis into a more formal description of the relationships between environmental regulations and innovation: 'by stimulating innovation, strict environmental regulations can actually enhance competitiveness'. A case in point: firms induced to innovate in a new environmental policy setting will enjoy a first-mover (or an early-mover) advantage in the market ([Quitow, 2013](#); [Ziesemer, 2013](#)). At the same time the reduction of pollution often induces firms and nations to improve their productivity in terms of refiguring their resource usage towards more economically and ecologically sound practices ([Desrochers, 2008](#); [Barbiroli, 2011](#)). This would, thus, lead to a win-win situation, that is, better environmental and financial performance ([Esty and Porter, 1998](#)).

Subsequent research has defined three differing versions of the Porter Hypothesis:

- environmental regulations induce innovation (strong)
- certain types of environmental regulations induce innovation (narrow)
- environmental regulations induce environmental innovation (weak).

Among the first, [Adam Jaffe](#) together with his colleagues ([Jaffe et al., 1995](#); [Jaffe and Palmer, 1997](#)) took upon the task to empirically test (by summarising the statistical relationships between environmental regulations, innovative activity and industry performance) the statements by Porter concluding that there is relatively little evidence supporting the hypothesis. However, evidence supporting the opposite hypothesis of adverse impacts was also found negligible. Therefore, the true impact of environmental legislation on innovativeness and competitiveness seems to lie in between these two extremes of this economic debate ([Jaffe et al., 1995](#)). Accordingly, although they found

no evidence supporting an actual increase in inventive output, their data indicated that at least the R&D expenditures seem to grow through compliance to environmental legislation (Jaffe and Palmer, 1997). Since the works of Jaffe and his colleagues, several authors have continued to concentrate their attention to empirically testing and modelling the hypothesis (Table 1).

Table 1 A summary of the reviewed studies empirically testing the Porter Hypothesis

<i>Authors</i>	<i>Concluding remarks on the Porter Hypothesis</i>	<i>Overall assessment on the feasibility of the Porter Hypothesis</i>
Jaffe et al. (1995)	The truth regarding the relationship between environmental protection and international competitiveness lies in between the two extremes of the current debate	+/-
Jaffe and Palmer (1997)	Data at the industry level are mixed with respect to the hypothesis that increased stringency of environmental regulation spurs increased innovative activity by firms	+/-
Heyes and Liston-Heyes (1999)	The net costs are lower than conventionally thought	+
Xepapadeasa and de Zeeuw (1999)	A stricter environmental policy cannot be expected to provide a win-win situation in the sense of both reducing emissions and increasing profitability in an industry, but may increase productivity along with a relatively less severe impact on profits	+/-
Ambec and Barla (2002)	An environmental regulation may enhance pollution-reducing innovation and at the same time increase firms' private benefits	+
Mohr (2002)	Endogenous technical change makes the hypothesis feasible	+
Murty and Kumar (2003)	The technical efficiency of firms increases with the degree of compliance of firms to the environmental regulation thereby supporting the hypothesis	+
Roediger-Schluga (2003)	The strictest standards had no clear negative or positive impact	+/-
Managi (2004)	This study finds evidence to support for a recast version of the hypothesis, but rejects a standard version of the hypothesis	+/-
Feichtinger et al. (2005)	Implementing a stricter environmental policy has a strong negative effect on industry profits, which implies quite the opposite as to what is described by the hypothesis	-
Höglund Isaksson (2005)	Evidence gives little support for the presence of true win-win opportunities	-
Crotty and Smith (2006)	This analysis shows no support for the hypothesis.	-
Greaker (2006)	An especially stringent policy may be welfare enhancing	+
Lanoie et al. (2008)	The hypothesis is confirmed only for some industries	+/-
Mohr and Saha (2008)	Examples presented are fully consistent with the hypothesis	+

Table 1 A summary of the reviewed studies empirically testing the Porter Hypothesis (continued)

<i>Authors</i>	<i>Concluding remarks on the Porter Hypothesis</i>	<i>Overall assessment on the feasibility of the Porter Hypothesis</i>
Triebswetter and Wackerbauer (2008)	Results yield supporting evidence for the hypothesis: environmental legislation stimulates innovation and leads to win-win situations	+
André et al. (2009)	The implementation of a green policy may enhance the environmental quality of the product and simultaneously increase firms' private profits	+
Kriechel and Ziesemer (2009)	The hypothesis holds even for profit-maximising firms	+
Rassier and Earnhart (2010)	Tighter regulation lowers profitability	-
Lanoie et al. (2011)	The analysis shows: strong support for the 'weak' version, qualified support for the 'narrow' version, but no support for the 'strong' version of the hypothesis	+/-
Antonioli et al. (2013)	The evidence is coherent with the hypothesis	+
Broberg et al. (2013)	No support for the hypothesis was found	-
Gulbrandsen and Stenqvist (2013)	The study does not lend support to the hypothesis	-
Zhang and Choi (2013)	The results support the hypothesis	+

After more than two decades of extensive work, the research on the validation of the Porter Hypothesis has not produced a consensus (Iraldo et al., 2011; Ambec et al., 2013): some studies are in favour of and some against the statements by Porter, whereas others remain inconclusive. This discussion is closely related to the dissonance between different empirical measures of innovation (Wagner, 2007). Most proxy indicators, such as R&D, patents and other input measures of innovation, are not confidently linked to innovation outputs. In short, not all innovative efforts lead to actual innovation to be introduced to the markets. This is particularly problematic, if the time lags between regulations and innovation outputs are not taken into account. Therefore, on a statistical sense, the validation or dis-valorisation of the Porter Hypothesis with traditional indicators and methods can be considered as extremely difficult. This leads to the problems of the chosen methodology: thus far the question has been mainly studied through econometric modelling and statistical analysis (Constantatos and Herrmann, 2011; Lambertini and Tampieri, 2012). However, in global scale, if some countries do not follow in setting environmental regulations (or to a much lesser extent), assessing Porter's case for enhanced competitiveness becomes highly problematic (Oberndorfer and Rennings, 2007). The inclusion of different approaches to form a more holistic picture of the economic impacts of environmental regulations and the interaction of environmental regulations with other government policies are still missing (Kemp and Pontoglio, 2011). Moreover, the issue of different policy instruments' impacts on the

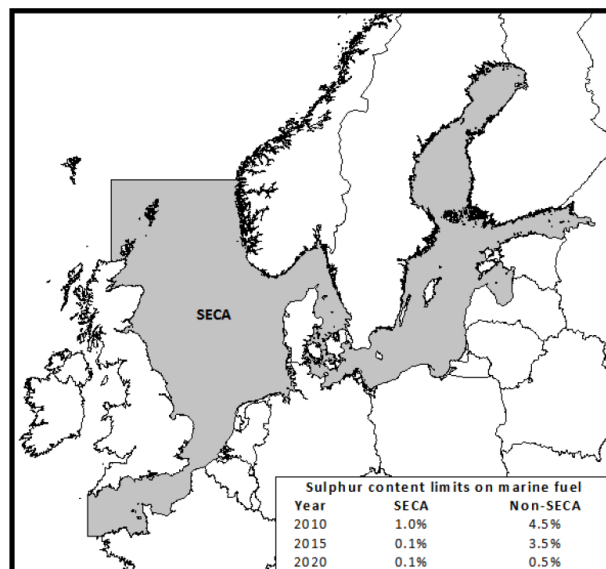
innovation performance of the society as a whole is still an issue just becoming to gain momentum among the innovation literature (Veugelers, 2012). The need for more interdisciplinary approaches is, thus, well justified.

3 The impacts of IMO regulations for prevention of air pollution from ships

3.1 Economic, environmental and health impacts of IMO regulations

On 10 October 2008 IMO Annex VI of the MARPOL Convention agreed to reduce emissions of shipping by regulating the sulphur content in marine fuel (IMO, 2008). After a while, the issue rose also to the fore of policy and public interest. In Northern Europe the Baltic Sea, the North Sea and the English Channel were designated as a SECA with stringent limits for sulphur content in marine fuel to be effective in 2015 (Figure 1). In practice, this imposes ships operating in the SECA to use different fuel, more expensive LSF, or marine scrubber systems, when entering the SECA. Furthermore, the document (IMO, 2008) includes a nitrogen oxides reduction scheme for new ships. The possibility of proposing the Baltic Sea and North Sea as NECA, i.e., Nitrogen Emission Control Area, have been under investigation, but at the moment the designation of Northern European NECA has been postponed. Accordingly, IMO is also committed to reducing Greenhouse Gas (GHG) emission by supporting the implementation of mandatory measures to increase energy efficiency.

Figure 1 The geographical and regulatory features of the Northern European SECA according to IMO (2008)



The impacts of the IMO regulations are most relevant in the maritime sector (shipping and maritime industry firms of the countries adjacent to the SECA) and in the export/import-oriented industries, since shipping industries are likely to transfer most of

its increased costs to the customers. It will also have wide-ranging indirect effects on the society as a whole: in an integrated world with increasing volume of global trade and technological development in transport, environmental regulations can have a decisive role in shaping countries' comparative advantages (De Santis, 2012). Therefore, the economic impacts of IMO regulations have been estimated in countries heavily relying on sea transport in their foreign trade. Table 2 presents a summary of the estimated costs and expected impacts on modal shift of implementing IMO regulations in the Northern European SECA. The estimations, despite a few exceptions, have concluded in somewhat bleak descriptions of rising transport costs significantly complicating the life of export-based firms as well as industries relying on non-domestic inputs. Furthermore, it is expected, that increasing shipping costs will lead to substantial modal shifts from maritime transport to road (and rail) transport, increasing the traffic load on the already overcrowded road infrastructure and adding to the output of GHG emissions. Therefore, the regulations (as well as the measures targeted at reducing GHG emissions of shipping and the plans to establish the Northern European NECA) have been generally met with reservations (or even dissatisfaction and resistance) by national governments and, in particular, by the private sector of the Northern European countries.

Table 2 A summary of the reviewed studies estimating the costs and modal shift impacts of implementing IMO regulations in the Northern European SECA

<i>Authors/Organisation</i>	<i>Summary of economic and modal shift estimations</i>	<i>Overall assessment on the impacts</i>
AEA (2009)	Costs (scrubbing and fuel costs) and benefits (emission reduction) of SECA: For all scenarios benefits will exceed costs	+
Entec (2009)	Costs and benefits (for all vessels) of SECA: Depending on the estimate, annual costs exceed the annual health benefits by a ratio of 3/8 or 1/5	-
Kalli et al. (2009)	The impact of SECA on Finland's foreign trade: Significant negative impacts on Finland's foreign trade and to export/import extensive industries	-
Swedish Maritime Administration (2009)	The impact of SECA on shipping at Swedish ports: The total increased costs exceed the corresponding socio-economic benefit by a ratio of 1/3. For passenger ferry traffic (example: Stockholm-Turku) the additional costs exceed the socio-economic benefit by a ratio of 1/14	-
COMPASS (2010)	The impact of SECA on modal shift: Modal shares decrease for all ship types (shift towards road and rail traffic)	-
ISL (2010)	The impact of SECA on modal shift in Germany: A significant shift from sea to land transport in the container shipping segment and in terms of trailers and trucks	-
Notteboom et al. (2010)	The impact of SECA on freight rate: An increase in the freight rate amount from 8–25% (low fuel price scenario) up to 20–40% (high fuel price scenario)	-
SKEMA (2010)	The impact of SECA on modal shift: A sample of RoRo routes predicts an approximate 10% loss in cargo volumes from RoRo to road/rail alternatives	-

Table 2 A summary of the reviewed studies estimating the costs and modal shift impacts of implementing IMO regulations in the Northern European SECA (continued)

<i>Authors/Organisation</i>	<i>Summary of economic and modal shift estimations</i>	<i>Overall assessment on the impacts</i>
European Commission (2011)	The wider monetised impacts on health are generally expected to exceed costs	+
Kalli et al. (2012)	The impact of SECA on externalities for the Gulf of Finland: The total fuel cost will be increased by €50 million, whereas the benefits obtained in externalities will be only €10 million	–
AMEC (2013)	The impact of SECA on modal shift in the United Kingdom: The scale of harm to the UK (from modal shift) is substantial, leading to negative economic and employment effects	–
Johansson et al. (2013)	The impact of SECA on fuel costs: The increase in fuel costs for shipping will vary between 13% and 69% depending on the development of the prices of fuel and the use of the sulphur scrubber equipment	–

It is generally accepted that the health and environmental benefits of reducing sulphur content in marine fuel are considerable and that air pollution from shipping causes severe health impacts globally. Additionally, there is a significant damage to ecosystems and cultural heritages. For example, [Corbett et al. \(2007\)](#) has estimated that annually 60,000 premature deaths, globally, can be contributed to shipping, whereas [Brandt et al. \(2011\)](#) have estimated that in Europe alone as many as 49,500 deaths in 2000 were related to shipping exhaust emissions, and that the number of deaths will rise to 53,400 in 2020. Accordingly, the positive effects of emission control of sulphur oxides (SO_x) on both air and water quality as well as on human health are already well estimated, monitored and documented ([European Commission, 2011](#); [Kalli et al., 2012](#)). In this respect, the implementation of IMO regulations is well justified. However, despite a high demand for analysis of environmental policy outcomes there is relatively little theoretical research on the issue ([Enevoldsen, 2005](#)). Earlier research has also highlighted the importance of empirical work in assessing environmental policy performance ([Hammond et al., 1995](#); [Dasgupta et al., 2001](#)). Therefore, discussion on environmental regulations and their economic impacts by combining both theoretical and empirical strands of thought is called for.

3.2 *An example of the innovation inducement impact of IMO regulations: marine scrubber systems*

An already used practise (new way of doing things)—that can remarkably reduce fuel consumption of specific ship types—in maritime traffic is slow steaming ([Kontovas and Psaraftis, 2011b](#)). According to [Cariou \(2011\)](#) slow steaming has reduced emissions in international containership traffic by ~11% over the past few years. In fact, in containerships up to 70% decrease in emissions can be achieved when the speed is halved ([Corbett et al., 2009](#)). However, larger number of ships may be needed to reach the same annual cargo turnover as without slow steaming. Other possible examples of innovations induced by environmental regulations include, for example, energy-saving

engines and more efficient propulsion (Psaraftis and Kontovas, 2010), but these kinds of ‘upgrades’ are commonly considered as incremental improvements (Makkonen et al., 2013).

A more concrete example of the (product) innovation inducement impact of IMO regulations is that of marine scrubber systems. With the aid of seawater, freshwater or dry scrubber systems, ship owners see an opportunity to avoid the high cost of switching from relatively cheap heavy fuel oil (HFO) to costlier LSF–marine gas oil, marine diesel oil or liquefied natural gas (LNG). Marine scrubber systems could also help the oil industry to avoid the investments that would be needed to convert HFO to cleaner alternatives. Scrubber systems remove harmful compounds from exhaust, which would otherwise pass through the atmosphere and end up polluting the environment (Kalli et al., 2009). Scrubber systems have a long history in industry, but they have not been used in ships for that long (Henriksson, 2007): it required extensive technological R&D and technical adjustments to find solutions for fitting scrubber systems into ships. Commonly, scrubbers take the form of a cylinder tower into which combustion gases are fed and subsequently cleaned. There are, in principle, two types of scrubber systems:

- wet scrubbing technologies, which are based on fresh water added with alkaline (‘closed-loop’ concept) or sea water (‘open-loop’ concept), depending on the wash water inherent quality in the area
- dry scrubbing technologies, in which the exhaust gas is conveyed through a layer of dry calcium hydroxide pellets.

These technological aspects of marine scrubber systems have been discussed in greater detail in a recent assessment by Lappi et al. (2012).

Marine scrubber systems can be retrofitted in existing vessels and installed in new-buildings on certain conditions: the cleaning efficiency of the unit and its size, which is in proportion to how efficient it is. However, retrofit applies only to the wet scrubber systems, whereas dry scrubber systems are large and heavy, that is, hardly suitable for being retrofitted on board existing vessels (for examples of the installation and retrofitting of marine scrubber system see Danish Ministry of the Environment, 2012; Wärtsilä, 2014). Naturally, installing the equipment in existing vessels is a much more complex task than with new ships, where the necessary spatial solutions can be reckoned with already at the planning stage (Lappi et al., 2012). There are only a few manufacturers (including Alfa Laval, Clean Marine, Couple Systems, DuPont BELCO Clean Air Technologies and Wärtsilä) of wet scrubber systems, giving a competitive advantage to firms that took the early initiative in producing them (Kalli et al., 2009; ABS, 2013). In the case of dry scrubber systems there are, however, at the moment no such products commercially available (Lappi et al., 2012). The environmental and technical feasibility, that is, the efficiency to remove SO_x , of marine scrubber systems seems to be fairly good (Danish Ministry of the Environment, 2012; Caiazza et al., 2013). However, the literature on the economic feasibility of marine scrubber systems is scarce and the results, thus far, inconclusive (Table 3). In addition, when employing wet scrubber systems, after the process there is the problem of the washing water used in scrubbing: the carbon residue has to be cleaned and processed in waste disposal plants, increasing the overall costs. Moreover, as argued later by Gilbert (2014), the use of marine scrubber systems provides little incentives to move beyond the use of HFO altogether.

Table 3 A summary of the reviewed studies estimating the economic feasibility of marine scrubber systems

<i>Authors</i>	<i>Case</i>	<i>Economic feasibility of marine scrubber systems as a SO_x abatement method</i>	<i>Overall assessment on the feasibility</i>
Tzannatos (2010)	Greek seas	Strong support: The most cost-effective method for abatement	+
Kalli (2012)	Finland	Strong support: Using marine scrubber systems may even halve the additional costs	+
Yang et al. (2012)	Global	Low support: Alternative methods for abatement are more feasible in economic terms	–
Jalkanen et al. (2013)	Northern European SECA	Strong support: Using marine scrubber systems may decrease the overall additional costs by about 35%	+
Nikopoulou et al. (2013)	Northern European SECA	Moderate support: A financially attractive, but not the most cost-effective method for abatement	+/-
Jankowski (2013)	South Baltic Sea region	Low support: LNG is a far more cost-effective method for abatement	–

According to the early estimates it seems that the literature generally supports the economic feasibility of marine scrubber systems (Mazraati, 2011). Still, by using a sample of real ships that operate within the Northern European SECA, Nikopoulou et al. (2013) have argued that while conservative estimates suggest that the use of marine scrubber systems would constitute a financially attractive abatement option, the use of LNG is the most financially attractive alternative for emission abatement in the shipping industry. In a recent study, Jankowski (2013) has concluded in similar estimations, but with stronger statements on the superiority of LNG (arguably, because the study is a result of a project aimed at promoting the use of LNG). However, these estimations do not take into account the expensive infrastructure needed (LNG terminals) for supplying the ships with LNG. In a study by Yang et al. (2012), the changeover method and segregated tank design, that is, shifting to LSF when entering the SECA, was found (at the moment) to be the preferred options to control SO_x. Contrary, Tzannatos (2011) has calculated that, in relation to reducing SO_x emissions from shipping in the Greek seas, the application of marine scrubber systems is more cost-effective than the use of LSF. Similarly, according to Kalli (2012) and Jalkanen et al. (2013) using marine scrubber systems may even halve, or at the very least significantly decrease, the additional costs of responding to IMO regulations on sulphur content in marine fuel. However, for ships that rarely visit the Northern European SECA fuel switch is still a more economical solution (Jalkanen et al., 2013).

Marine scrubber systems were estimated to become more popular in the future due to the globally imposed limit of sulphur emissions: installing marine scrubber systems to vessels will become more attractive when we are closer to the global limit of 0.5% (Figure 1), planned to be realised in 2020 (Kalli, 2012; Yang et al., 2012). At the moment, for individual shipping companies, any estimation is sensitive to the ship itself (age and type), fuel prices and the share of operations inside the SECA (EMSA, 2010). Therefore, the decision on which emission abatement measures to apply has to be taken on ship-to-ship basis. Recent newspaper articles have discussed the feasibility of marine

scrubber systems revealing that their high price has been an issue for shipping companies, but that, according to industrial order books, the demand for marine scrubber systems has grown (after a period of procrastination) just before 2015 when the sulphur limits will take effect in the Northern European SECA (Talouselämä, 2014). Despite the uncertainty in the economic feasibility of the marine scrubber systems, they still constitute a clear example of a product innovation induced by stricter environmental regulations.

In a wider context, the negative impacts of the delineation of SECAs to cover a geographically limited area (as opposed to regions without strict regulations), could be considered as an advantage. The non-SECA areas will follow stricter regulations of SECAs later on (Figure 1). Therefore, the product, process and service innovations designed for SECAs in the first place, will be beneficial worldwide, thus giving the firms that produced them a first-mover advantage in the global markets, i.e., lead markets (Beise and Rennings, 2005; Huber, 2008). In the case of marine scrubber systems, the demand is bound to increase globally, if/when the stricter sulphur limits are imposed also to non-SECA regions.

4 Concluding remarks and directions for further research

In conclusion, it can be stated that the literature on the reviewed topics remain inconclusive and without clear consensuses. The extensive work on the Porter Hypothesis has produced a series of economic calculations with diverging results neither corroborating nor falsifying conclusively the original proposition on the innovation inducement impact of environmental regulations. Similarly, the economic impact assessments on the Northern European SECA have produced a variety of results ranking from bleak estimations of deteriorating national competitiveness and modal shift towards land transport to the more positive views suggesting that the wider positive societal impacts will exceed the costs: what is agreed upon is the fact that the environmental regulations will result in health and environmental benefits, but at what cost, remains debatable. Accordingly, the results shown for the North European SECA might not reflect the results in other SECAs: for example, the road network in other areas may not be able to serve the potential modal shift and therefore similar growth, as anticipated in the case of the Northern European SECA, in land transport volumes might never take place. Similar situation applies to marine scrubber systems: their benefits in terms of their efficiency to remove SO_x are almost unquestioned, but the economic feasibility of their use lacks a rich empirical literature and the few existing studies conclude in differing statements.

In light of this review, it is still worth exploring the Porter Hypothesis in greater detail. However, as a point of departure, here the inclusion of interdisciplinary approaches is encouraged, since this review has shown that the extensive amount of econometric modelling and statistical testing have not resulted in all-encompassing arguments. The amalgamation of different strands of thought and varying methods (both quantitative and qualitative) could possibly open up interesting new insights to this decades old debate. Accordingly, the calculations on the economic impacts of the Northern European SECA have to be revised (and compared with other current and future SECAs) with timely data, as it becomes available, to be better equipped to measure the effects of the stricter environmental regulations. Thus, far these assessments have had to rely on estimations. Moreover, the inclusion of theoretical discussion and conclusions on

the policy outcomes of environmental regulations are called for, since the estimations have so far (commonly) lacked these kinds of academic developments. Lastly, marine scrubber systems are positioned here as an interesting possibility to study the innovation inducement impact of the IMO regulations by thoroughly tapping into the development process of the marine scrubber systems and the firms producing them as well as into their economic feasibility according to, for example, industrial order books and sales statistics.

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