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Please cite this paper as:

Corbett, J. *et al.* (2016-03-25), "Environmental Policy and Technological Innovation in Shipbuilding", *OECD Science, Technology and Industry Policy Papers*, No. 28, OECD Publishing, Paris.
http://dx.doi.org/10.1787/5jm25wg57svj-en

OECD Science, Technology and Industry Policy Papers No. 28

Environmental Policy and Technological Innovation in Shipbuilding

James J. Corbett,

Nick Johnstone,

Karin Strodel,

Laurent Daniel

OECD

FOREWORD

This paper, prepared by Professor James Corbett, Nick Johnstone, Karin Strodel and Laurent Daniel, examines the relationship between environmental policy and 'green' innovation in shipbuilding. The primary motivating question of this work is whether there is evidence of: i) technology push from innovation that enables environmental policy initiatives; and/or, ii) policy pull that induces innovation leading to 'green' ships. This paper focuses on four environmental categories of technological innovation in the shipbuilding industry, encompassing oil spill recovery, emissions control, climate change mitigation and ballast water treatment. The analysis draws upon documents filed at the International Maritime Organization (IMO) to proxy for policy measures, and uses patent data of the Worldwide Statistical Patent Database, maintained by the European Patent Office (EPO), to account for innovation. Our results show a similar trend between patent activity and IMO document submissions over the years 1998 to 2012 for the two environmental categories, climate change mitigation and emissions control. The key contribution of this work are to provide more insights into environmental policy in shipbuilding and its role in innovation activity, as well as to develop a rich dataset focused on IMO policies aimed at encouraging improved environmental performance by ships.

Delegates of the OECD Council Working Party on Shipbuilding (WP6) discussed the report at their meeting on 10 November 2015 and agreed to declassify the report, after the addition of some comments, so that it could be made available to a wider audience. The report is also available on the WP6 website: www.oecd.org/sti/shipbuilding.

The authors wish to thank Mr Laurent Moussiegt for his valuable support to the data extraction from the Worldwide Statistical Patent Database, maintained by the European Patent Office (EPO).

Note to Delegations:
This document is also available on OLIS under the reference code:
C/WP6(2015)8/FINAL

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EXECUTIVE SUMMARY

The OECD Council Working Party on Shipbuilding (WP6) has been providing support to its member countries on issues related to the environmental sustainability, innovation and structural adjustment in the shipbuilding sector. To that end, the WP6 has been reviewing the policy actions likely to affect construction and operation of green ships, with a primary focus on energy efficiency and efforts to reduce carbon dioxide (CO_2) and other greenhouse gases (GHGs).

Under the Programmes of Work and Budget (PWB) for 2013-14 and 2015-16, the WP6 agreed to pursue analytical work on the assessment of policies to support environmental improvements in shipbuilding and to identify market conditions as well as policies that likely lead to "green" innovation in maritime transport. The OECD Secretariat, therefore, started this project to draw upon data on patents related to ‘green ships’, and to analyse the effects of policy conditions on innovation in this area.

The primary motivating question is whether there is evidence of technology push from innovation that enables environmental policy initiatives and/or policy pull that induces innovation. The truth is likely to lie somewhere in between, with policy initiatives inducing innovation, and vice versa.

This study draws upon documents filed at the International Maritime Organization (IMO) to proxy for policy measures. International environmental agreements achieved through consensus at the IMO may or may not be a typical driver for innovation relative to policymaking by national sovereign or subnational agency authorities with implicit enforcement capacities. However, such agreements are the primary means for implementing a coherent framework for setting global performance standards given the international nature of shipping. The key contribution of this work is to develop a rich dataset focused on policies aimed at incentivizing or directly requiring improved environmental performance by ships.

There exists a body of research in environmental economics that explore the theory and evidence around the idea that environmental policy interventions create new constraints and incentives that affect the process of technological development. In the presence of market failures policy interventions provide incentives for the development, diffusion and adoption of innovative products or processes, such as more energy-efficient ships or ballast water treatment devices, in cases of market failure. Therefore, in an empirical context, understanding how the technological change process responds to environmental policies provides useful information to firms and policymakers.

For this work, policy information includes: i) performance standards required for international shipping; ii) policies imposing reporting requirements and certifications of compliance; and, iii) to a limited extent available policy discussion related to market-based policy instruments such as tradable permits. Importantly, induced technological change in one industry sector may not result exclusively in innovations from within the sector affected.

This work examines innovation and policy interactions using data aligned with several environmental issues affecting international shipping. These include:

a) Oil spill prevention and recovery.

b) Emissions control, representing two separate but related policy objectives

   i Air pollution control technologies, e.g., exhaust scrubbers for sulphur, specialized low-emission engine technologies and cleaner fuels;
   ii Climate change energy efficiency technologies, e.g., addressing GHGs, and/or in support of energy efficiency design index policies.

c) Ballast water treatment to prevent or reduce the risk of aquatic species invasions.

d) Other environmental issues (not included in the analyses, but presented for descriptive purposes)

   i Hull fouling treatment to reduce the risk of aquatic species invasions;
   ii Noise, e.g., on-board noise controls for health and safety, and underwater noise management;
   iii Regional integration of environmental protection (i.e., Polar Code).

Importantly, environmental policies targeting an industry where environmental standards may have lagged relative to other industries or sectors with similar technologies could promote diffusion and adoption as distinct from innovation. The use of patent data obviates this problem. Patent data was obtained from the Worldwide Statistical Patent Database, maintained by the *European Patent Office* (*EPO*), for all available years, inclusive of 1900 to 2013. The IMO committees and decision bodies make available through the IMO document repository (IMO Docs) a series of reports, delegate position papers for member nations and participating non-governmental organizations, working documents prior to decisions, decision documents, and other publications. These data support exploratory analysis of relationships among different technology types and IMO document groups, by environmental issue.

A number of questions are tested with regard to comparisons of the patent data sets related to technology types:

- Can we expect trends in green technology development in the sector, as measured by patent activity, to be similar to overall patent activity for ship and waterborne technologies?
- Can we expect evidence of environmentally focused patents in one domain to be correlated with patent activity in other environmental domains?
- Can we observe relationships between patent activity for maritime environmental technologies and policy activity at IMO, as measured by issue-specific document counts?

Patent data comparisons. Examination of correlations suggests that patterns and trends in green technology development, as measured by patent activity, differ from overall patent activity for ship and waterborne technologies. However, the patent data indicates that there are different trends and patterns for different environmental technology types. This could suggest different levels of innovative activity, technology diffusion of existing inventions, or weaker policy drivers for some environmental issues related to international shipping.

Comparison of patent data and IMO documents. Correlations between patents and IMO documents are positive and high for some issues, such as climate change (and emissions), but negative for air pollution patents, and for oil pollution. Other correlations, notably those for ballast water technologies, are generally positive but not strong. There may be some indication that air pollution patents respond differently to policy development at IMO, and that recent oil pollution policy development is not related to patent activity that may be motivated by other drivers.

For climate change, policy attention on energy efficiency in the current decades is aligned with industry goals regarding better vessel performance, energy efficiency, and cost containment. There is some indication that these policies may not yet be constraining, leading to incremental change with existing technologies in combination with a degree of technological change. Additional research is needed as the IMO policies on the energy efficiency design index (EEDI) and ship energy efficiency management plan (SEEMP) enter into force to determine whether environmental policy for shipping among the aligned drivers is statistically significant and/or potentially technology-forcing.

Ballast water policy development at IMO appears to present an intuitive example of technology-forcing policy, or conversely, innovation-enabled policy. However, two possible conditions may explain less significant relationships. First, the current Ballast Water Convention is not yet fully ratified and has not entered into force. Second, the performance standards under the Ballast Water Convention impose treatment by filtration and/or active substances that may not require new patents. In fact, an October 2015 court finding (United States Court of Appeals for the Second Circuit, 2015) provides evidence that *Ballast* Water Management (BWM) standards are not strict enough to constrain existing technology or motivate sufficient innovation of new technology.

Oil spill prevention and response policy documents may imperfectly correlate with innovation in oil spill technologies for two reasons. First, environmental policy action at IMO to control oil pollution was a key issue in the original development of the International Convention for the Prevention of Pollution from Ships (MARPOL) in 1973/74, resulting in a global transition to double hull designs which was largely completed by the window for this analysis. Second, the patent search conducted for this project focused on oil spill recovery technologies which may outside the jurisdiction of IMO – focused mainly the safety and security of shipping and the prevention of marine pollution by ships. Additional data are needed for both patent activity and oil spill policy time-series development.

While environmental policies can induce technology innovation, it would appear that IMO standards alone are not yet stringent enough to produce technology-forcing behaviour across all aspects of green ship design. Existing or pending international agreements for ships often have long phase-in periods, after ratification and entry into force, that move into the future some important environmental constraints that may prove to be technology forcing. To fully evaluate maritime environmental technology-policy in terms of innovation, therefore, future work would need to interpret policy action to promote greener ships in terms of new and novel innovations, technology diffusion of innovations from other sectors, technology adaptation without novel innovations, and techno-operational changes within a sphere of existing technologies.

LIST OF ABBREVIATIONS

BAT	Best available technology
BLG	Subcommittee on Bulk Liquids and Gases, at IMO
BWE	Ballast water exchange
BWM	Ballast Water Management
CH_4	Methane, a GHG
CO_2	Carbon dioxide, a GHG
DE	Subcommittee on Design and Equipment, at IMO
DNV	Det Norske Veritas
EEDI	Energy efficiency design index
EPA	United States Environmental Protection Agency
EPO	European Patent Office
GDP	Gross domestic product
GHG	Greenhouse gas
IEA	International Environmental Agreements
IMO	International Maritime Organization
IMODocs	IMO document repository (docs.imo.org/)
ISO	International Organization for Standardization
LNG	Liquefied natural gas
MARPOL	International Convention for the Prevention of Pollution from Ships
MEPC	Marine Environment Protection Committee, at IMO
N_2O	Nitrous oxide, a GHG
NOx	Oxides of nitrogen, an air pollutant and contributor to ozone pollution
O_3	Ozone, an air pollutant produced from reaction of NOx and VOC in presence of sunlight
ODS	Ozone depleting substances
OECD	Organization for Environmental Cooperation and Development
PATSTAT	Worldwide Patent Statistical Database
PPR	Subcommittee on Pollution Prevention and Response, at IMO
R^2	Coefficient of determination, indicating how well data fit a statistical model
R&D	Research and development
SAB	U.S. EPA Science Advisory Board
SDC	Subcommittee on Ship Design and Construction, at IMO
SEEMP	Ship energy efficiency management plan
SOLAS	International Convention for the Safety of Life at Sea
SOx	Oxides of sulfur, an air pollutant and contributor to acidic particle deposition
TBEL	Technology based effluent limit
UNCTAD	United Nations Conference on Trade and Development
VOC	Volatile organic compounds
WP6	Working party on shipbuilding, OECD

ENVIRONMENTAL POLICY AND TECHNOLOGICAL INNOVATION IN SHIPBUILDING

1. INTRODUCTION

The OECD Council Working Party on Shipbuilding (WP6) has been providing support to its member countries on issues related to environmental sustainability, technological innovation and structural adjustment in the shipbuilding sector. To that end, the WP6 has been reviewing the policy actions likely to affect construction and operation of green ships, with a primary focus on energy efficiency and efforts to reduce carbon dioxide (CO_2) and other greenhouse gases (GHGs).

The WP6 included in its Programmes of Work for 2013-14 and 2015-16 an item aiming at better understanding the factors driving the construction and operation of green ships. WP6 has identified innovation as one of the most important factors with regard to better environmental performance by ships. The OECD Secretariat, therefore, started this project to draw upon data on patents related to green ships to analyse the effects of policy conditions on innovation in this area.

Data on patents to be used in this project were drawn from the latest version of the OECD/European Patent Office (EPO) Worldwide Patent Statistical Database (PATSTAT). Data on environmental policies affecting international shipping were developed after a survey of several sources, including international environmental agreements and limited review of European Union, United States, and other national policy actions. Based on the recognition that international shipping is only partly regulated by individual nations or multinational regional agreements, and recognizing that most of State-level regulations and standards for environmental performance are derived from international agreements at the International Maritime Organization (IMO), a detailed investigation was conducted into policy documents submitted to the IMO.

In this report evidence garnered from these two sources is presented. The long-term intention is that these data and this report can inform future research to better understand the nature and potential for environmental technology innovation and adoption in international shipping, and the construction and operation of 'green ships' in the coming decades.

1.1 General overview

The primary motivating question is whether there is evidence of technology push for innovation that enables environmental policy and/or policy pull that creates incentives for innovation.[i] This work is exploratory in nature, in some ways pioneering investigative work that will enable strategic follow-on research that is rigorous and provides more advanced decision policy insights with regard to the interactive roles of shipping activities, maritime policy, and technology innovation.

The approach taken in this work is founded on the premise that patent data and policy actions are linked. Most generally, patent activity has been considered and demonstrated to be one metric for technological change as discussed in Section 2.1. This depends firstly upon the expectations that technological change is a representation of innovation or inventiveness and that patents serve as a quantitative metric by which to measure this (OECD, 2009). Second, environmental policies or regulations are among the many market and non-market drivers for innovations leading to patents

(Beerepoot and Beerepoot, 2007; Lee et al., 2011; Rothwell, 1980). The nature of the linkages among environmental policies and innovation have been argued with case-specific contexts to be positive, i.e., environmental norms and standards are factors stimulating innovation (Beerepoot and Beerepoot, 2007; Lee et al., 2010) or negative, i.e., environmental policy compliance is associated with decreased innovation (Rothwell, 1980, 1992).

International environmental agreements achieved through consensus at IMO may or may not be a representative proxy indicator of policymaking by national sovereign or sub-national authorities. However, such agreements are the primary means for implementing a coherent framework for setting global performance standards given the international nature of shipping. Many international environmental agreements rely upon consensus and ratification and therefore have not been evaluated in relation to technology innovation, either as stimulus or barrier. International shipping environmental policies are primarily forged through negotiated agreements at the IMO, based on consensus language and subsequent ratification that is then implemented through regulation by national, subnational, and regional authorities. Where environmental regulations for international shipping have originated outside the IMO unilaterally or multilaterally, these actions often shape subsequent IMO policy agreements.[ii] In both cases, the instruments of enforcement and compliance verification reside with port state, flag state, and other authorities that may participate in the diplomatic processes at IMO. Therefore, international environmental policies that codify and promote advances in ‘green shipping’ would need to be stringent enough to require original innovation, as opposed to the adaptation or diffusion of technology, to achieve performance goals or meet standards.

This issue is explored by developing initial data sets for staged testing of specific questions and hypotheses. The patent data provided for this work is in summary form, pending future work to develop quality metrics. The international policy data for this work represents its first use in the context of quantitative research into innovation and policy relationships. The key contribution of this work is to develop a rich dataset focused on policies aimed at incentivizing or directly requiring improved environmental performance by ships.

1.2 Organization of report

This report begins with a discussion of the analytical theory and approach to using patent and policy data to identify potential links between environmental policy development and technological innovation, in Section 2. The key data products developed for this work are described in Section 3, including descriptive data on innovation (i.e., patent data set) and descriptive data on environmental policy action (i.e., IMO policy documents), and other descriptive data such as economic data, trade data, and marine fuel price data. The exploratory quantitative analyses conducted are presented in Section 4. Section 5 presents discussion and reflection on the analyses results. Section 6 presents conclusions and recommended next steps to fully evaluate innovation and policy linkages in international shipping. References are provided in Section 7, and an Appendix includes data considered ancillary to the main report.

2. OVERVIEW DISCUSSION OF ANALYTICAL THEORY AND APPROACH

This Section presents an overview of the analytical theory behind the use of patents and policy data for quantitative investigation of linkages between innovation and environmental stewardship.

2.1 Innovation and environmental policy

There exists a body of research in environmental economics that explore the theory and evidence around the idea that environmental policy interventions create new constraints and incentives that affect the process of technological developments (Jaffe et al., 2002). In its theoretical form, the process of technological change moves from invention, the creative construct of a technology product or process based on an idea, through innovation, accomplished when the newly invented product or process is commercialized, to diffusion, where the technology achieves wider adoption and broad use (Jaffe et al., 2002; Mokyr, 1990). The presence of knowledge spill-overs means that market conditions do not provide firms with sufficient confidence of profit for improved technological inventions to be commercialised despite the opportunity for public benefits. The enforcement of intellectual property rights is one means of marrying private incentives with public benefits. However, in the environmental sphere, there is a second failure which retards innovation - the absence of property rights for environmental goods. Public policy theory suggests that where the market fails to produce a needed product or process, such as more energy efficient ships or ballast water treatment devices, policy interventions can do so. Therefore, in an empirical context, understanding how the technological change process responds to environmental policies provides useful information to firms and policy bodies.

Patents provide a measure of technological change with regard to induced innovation literature (Aghion et al., 2012; Dechezleprêtre et al., 2011; Johnstone et al., 2010; Popp, 2001, 2006). The advantages and drawbacks of using patents as a measure of innovation are well understood (Griliches, 1990). Patent-based statistics can represent the inventiveness of countries, regions, firms or individual inventors, under the assumption that patents reflect inventive output and that more patents mean more inventions (OECD, 2009). Patents represent broad ranges of technologies, with a close link to invention, over a long time series that can be publicly accessed and grouped in useful ways to represent connections to specific sources and types of invention. However, researchers have acknowledged drawbacks in using patent data to infer technological change. The use of patents as an indicator of technological change depends importantly on the number patents, and value of the patented ideas, and a clear understanding of the time intervals between patenting and commercialization (Basberg, 1987).[iii]

The literature is not in uniform agreement whether environmental policy achieves technological change and/or innovation through so-called technology forcing effects (Beerepoot and Beerepoot, 2007; Lee et al., 2010; Nentjes et al., 2007; Rothwell, 1980, 1992). Whereas researchers such as Nentjes et al. (2007), define environmental technology-forcing standards to be “standards which require a higher rate of emission reduction than currently available ‘off-the-shelf’ technologies can offer” (Nentjes et al., 2007), other considerations offer expanded interpretations of policies that are environmental technology forcing.

Importantly, induced technological change in one industry sector may not result exclusively in the traditional three-stage process described above. Environmental policies targeting an industry where environmental standards may have lagged relative to other industries or sectors with similar technologies could promote diffusion and adoption as distinct from invention. Environmental performance improvements in shipping, specifically the several categories of environmental performance studied for this report may be achieved through a combination of induced innovation and adaptive diffusion of existing technologies.

Economic theory suggests the most cost-effective environmental policies are ones which give polluters the flexibility to identify the most appropriate means of abatement for their circumstances and which equalise marginal abatement costs across different sources. On this basis market-based instruments are often proposed. (Hahn 1989, Kolstad 2015.) Such measures are also thought to be more effective in inducing innovation, precisely because they allow for flexibility in the achievement of a given environmental objective, inducing "search" for innovative solutions. (See Johnstone et al. 2010a). Such measures will also be economically efficient if the marginal costs of abatement are equal to the marginal damages. However, this is dependent upon being able to value the marginal damages, which Kageson (1999) has argued can be particularly difficult in the case of shipping. If so, the costs to industry may not be a) optimal in terms of Pigouvian principles; nor b) large enough to promote innovating research and development. Moreover, there may be weaker correlations depending upon the degree to which compliance is enforced.

Policy instruments with environmental objectives can be constructed in many different ways. Tarui and Polasky (2005) describe policy instrument relationships with firm-level innovation practices where there is uncertainty in environmental damages, and whether the policy is performance focused or standards-based. While Krysiak (2011) that certain policies can induce greater technological progress, some studies suggest that individual measures cannot be examined in isolation, and that a variety of policy actions need to be considered simultaneously[iv] Other research identifies the importance of what may be considered “regulatory learning”, where policies are updated upon learning new information (Tarui and Polasky, 2005).

This report focuses on a small number of policy measures. It does not evaluate research and development policies, investment or tax incentives, tariffs or trade policies, or other policy instruments that have been related to environmental innovation. The policy information assessed includes primarily performance standards required for international shipping, secondarily policies imposing reporting requirements and certifications of compliance, and to a limited extent market-based policy instruments such as permit trading.

2.2 International shipping and technology policy

The WP6 began studying policy actions likely to affect construction and operation of green ships, with a primary focus on energy efficiency and climate change efforts to reduce carbon dioxide (CO_2) and other greenhouse gases (GHGs). In 2013, the WP6 discussed five policies related to reducing CO_2 from ships (Det Norske Veritas (DNV), 2013). These included national or subnational policies to promote fuel infrastructure, impose financing requirements to include energy efficiency criteria, incentivize environmental research and development, adopt economic instruments such as port fees and efficiency rating reporting, and require government procurement practices that include logistics (i.e., fleet) reporting of CO_2 performance. These were studied as complements to existing and planned international regulation. This study adds to prior WP6 discussions by considering more directly the set of existing and planned environmental policies for international shipping.

While unilateral government action can produce environmental benefits, these are enhanced by international agreements (Det Norske Veritas (DNV), 2013). In some cases shipping environmental standards may be possible only through international cooperation on policy action. This project accessed and reviewed the International Environmental Agreements (IEA) Database Project (Mitchell, 2012-2015), which fosters analysis of IEAs by providing a repository. This dataset contains a summary of multilateral environmental agreements, from which a Marine Pollution subset was obtained. Figure 1. presents a summary of IMO environmental agreements and amendments a) by key environmental issue, and b) by issue and year of agreement or amendment. The approach followed in this document consists of using the number of documents as an indicator for the level of interest of

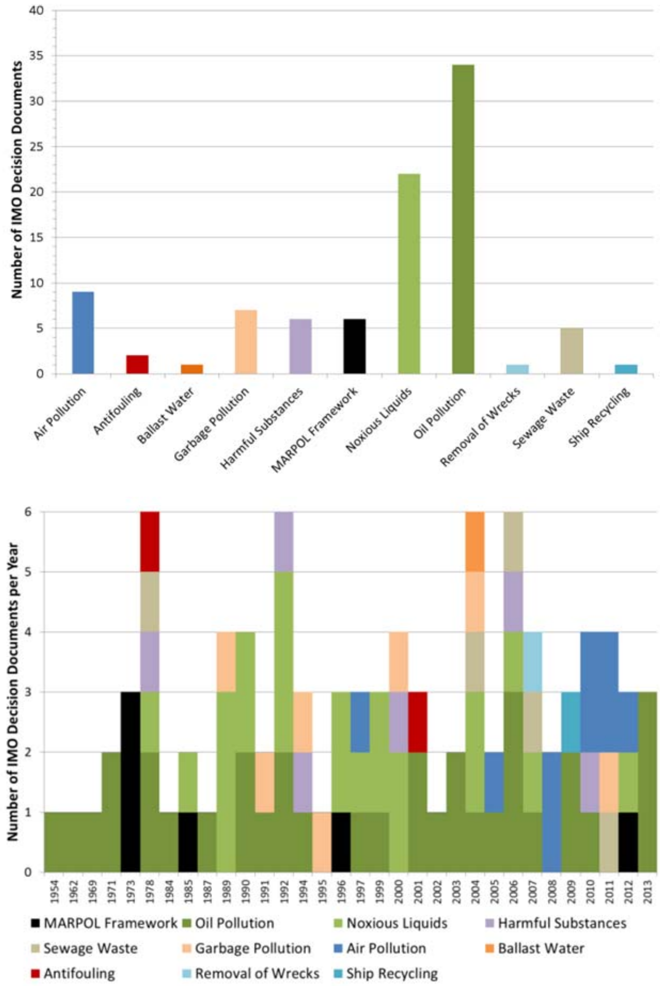
IMO member countries for specific environmental policy priorities. Documents include submittals by national delegations favouring stricter policy action, and by delegations advocating for less strict technology standards.

The process of establishing IMO standards through consensus necessarily involves a dialogue among delegations with diverse motivations and interests. Therefore, these documents may not narrowly represent national delegations with interests in promoting technology innovation or taking supporting positions on specific policies. Nonetheless, stricter policy standards or implementation timelines are associated with this measure of the "intensity of policy interest" in the development of new environmental regulation for international shipping.

Figure 1. Summary of IMO decision documents by (a) type of environmental issue; and (b) issue and year (IEA dataset)

(a)

(b)



Source: IMO documents at https://webaccounts.imo.org/

The IEA Database Project contains information on the lineage for the policy. The primary resource for policy documents related to international shipping technology is the International Maritime Organization (see http://www.imo.org/en/About/Pages/Structure.aspx).

> "The IMO consists of an Assembly, a Council, and five main Committees: the Maritime Safety Committee; the Marine Environment Protection Committee; the Legal Committee; the Technical Cooperation Committee and the Facilitation Committee and a number of Sub-Committees support the work of the main technical committees. … The MEPC, which consists of all Member States, is empowered to consider any matter within the scope of the Organization concerned with prevention and control of pollution from ships. In particular it is concerned with the adoption and amendment of conventions and other regulations and measures to ensure their enforcement. The MEPC was first established as a subsidiary body of the Assembly and raised to full constitutional status in 1985."

This work examines innovation and policy interactions using data aligned with several environmental issues affecting international shipping. These include:

a. Oil spill prevention and recovery
b. Emissions control, representing two separate but related policy objectives
   - i Air pollution control technologies, e.g., exhaust scrubbers for sulphur, specialized low-emission engine technologies and cleaner fuels
   - ii Climate change energy efficiency technologies, e.g., addressing GHGs, and/or in support of energy efficiency design index policies
c. Ballast water treatment to prevent or reduce the risk of aquatic species invasions
d. Other environmental issues (not included in Section 3 data or Section 4 analyses)
   - iii Hull fouling treatment to reduce the risk of aquatic species invasions
   - iv Noise, e.g., on-board noise controls for health and safety, and underwater noise management
   - v Regional integration of environmental protection (i.e., Polar Code)

Oil spill regulations were among the first environmental policies enacted by the IMO under International Convention for the Prevention of Pollution from Ships (MARPOL). The MARPOL Convention was adopted in 1973, with 1978 protocols, and is therefore often cited as MARPOL 73/78 (International Maritime Organization, 2002). It is a framework convention for a subsequent set of six agreements set in optional annexes and their amendments that enable policy actions to be updated through a consensus process.[v] Provisions for action are contained in Annexes I through VI, with Annexes I and II relating mostly to oil spill prevention and response. Prohibition of discharge of oil and noxious liquid substances, discharge criteria, and subsequent requirements such as double-hull designs for liquid bulk vessels (i.e. tankers) entered into force in 1983, followed by a number of amendments associated with respective implementation dates.

MARPOL Annexes III, IV, and V deal respectively with harmful substances carried by sea in packaged form, sewage by ships, and ship-generated garbage. Annex III entered into force in July 1992, revised in 2010 with entry into force in January 2014. Annex IV entered into force in September 2003, followed by revision adopted in April 2004, subsequently entering into force in August 2005. Annex V entered into force in December 1988 with optional compliance conditions; revisions were adopted in July 2011 and entered into force in January 2013, and developed guidelines for implementation including garbage management plans in 2012. These are not discussed as part of this WP6 scope.

Air pollution regulations at IMO are codified in MARPOL Annex VI (International Maritime Organization, 2008). Annex VI entered into force on 19 May 2005 and a revised Annex VI with significantly tightened emissions limits was adopted in October 2008 which entered into force in July 2010. Annex VI addresses emissions from ships, including engine system combustion products of oxides of sulfur (SOx), oxides of nitrogen (NOx), ozone depleting substances (ODS), volatile organic compounds (VOC), and shipboard incineration processes and their contribution to local and global air pollution and environmental problems.

MARPOL Annex VI adopted a new “Chapter 4 on energy efficiency of ships” in July 2011 (MEPC 62/24 and MEPC 62/WP.11/Add.1/Rev.1) which applies to most ships contracted for construction after 2017 and delivered after 2019. While not specifically referring to the reduction of GHG emissions [i.e. carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and ozone (O_3)], this document represents the first policy directly focused on energy efficiency as a driver of fossil fuel consumption and emissions from combustion. This was widely recognised as the first legally binding agreement to reduce CO_2 from international shipping, as attested to by remarks by the IMO Secretary General. Energy efficiency amendments to MARPOL VI entered into force in January 2013. The IMO describes two energy efficiency reporting and record-keeping requirements, the Energy Efficiency Design Index (EEDI) and the Ship Energy Efficiency Management Plan (SEEMP):

> “EEDI is a non-prescriptive, performance-based mechanism that leaves the choice of technologies to use in a specific ship design to the industry. As long as the required energy-efficiency level is attained, ship designers and builders would be free to use the most cost-efficient solutions for the ship to comply with the regulations. The SEEMP establishes a mechanism for operators to improve the energy efficiency of ships. Ships are required to keep on board a ship specific Ship Energy Efficiency Management Plan (SEEMP)”.[vi]

Ballast water management regulations developed in two stages, an earlier set of actions by IMO recommending voluntary ballast water exchange and supporting member nations’ efforts to require mandatory reporting, followed by eventual development of mandatory requirements including discharge performance standards that involve treatment technologies. The International Convention for the Control and Management of Ships' Ballast Water and Sediments (BWM Convention) was adopted in February 2004, and has yet to enter into force pending ratification by 30 states representing 35% of world merchant shipping tonnage. (As of September 2015, the convention is ratified by 44 nations representing 32.86% of world tonnage).[vii]

Three other environmental policy issues are under development at IMO. These include hull fouling, ship noise, and regional environmental protection of polar (Arctic) regions. While these are not in scope for this report, they are summarized below as potential future signals of environmental policy related technological change. Moreover, ship recycling and removal of wreck policy actions were not considered.

Hull fouling

There are efforts to understand and regulate the coupled problems of hull fouling, antifouling systems, and invasive species transported by ship hulls:

1. Control and management of ships' biofouling to minimize the transfer of invasive aquatic species, with guidelines adopted in July 2011. These guidelines provide a globally consistent approach to managing biofouling by providing useful recommendations on general measures to minimize the risks associated with biofouling for all types of ships.[viii]

2. Control of harmful antifouling systems, adopted 2001, entered into force September 2008. The Convention prohibits the use of harmful organotin in anti-fouling paints and prevents potential future use of other harmful substances in anti-fouling systems. Anti-fouling paints coat the bottoms of ships to prevent sea life attaching themselves to the hull – thereby slowing down the ship and increasing fuel consumption.

Underwater noise

Adopted Guidelines for the Reduction of Underwater Noise from Commercial Shipping (MEPC.1/Circ.833, April 2014) to reduce underwater noise from commercial ships were developed by the Subcommittee on Design and Equipment (DE 57) and approved by the MEPC (MEPC 66/17, November 2013). While these (as yet) are voluntary, they may provide policy signals for technological change and innovation. The non-mandatory Guidelines provide general advice:

- Recognise that shipping noise can have short- and long-term negative consequences on marine life, especially marine mammals;
- Recognise that technical and cost-effectiveness of measures considered, either individually or in combination, will be strongly dependent on the design, operational parameters, and mandatory requirements;
- Call for measurement of shipping noise according to objective standards maintained by the International Organization for Standardization (ISO), which are themselves on the verge of adoption;
- Identify computational models for determining effective noise control measures in new vessel design or fleet operation; and
- General advice about reduction of underwater noise to designers, shipbuilders and ship operators.

Polar (Arctic) protection

The International Code for Ships Operating in Polar Waters (Polar Code), as adopted, prescribes requirements primarily aimed to protect ships, seafarers, and passengers in the harsh environment of the waters surrounding the two poles. These requirements are mandatory under both the International Convention for the Safety of Life at Sea (SOLAS) and MARPOL. Early on, the policy process was focused on the opening access to the Arctic, and defined ambitions to include requirements for environmental protection and damage control in a special chapter of the Code (Subcommittee on Bulk Liquids and Gases [BLG] 7/11, July 2001). This effort was later deferred, although connection to MARPOL remains. Some stakeholders suggest that insufficient attention has been given to environmental protection issues in preparing mandatory components of the Polar Code (Marine Environment Protection Committee [MEPC] 68/INF.37, March 2015), mainly environmental response capacity as opposed to preventive measures. The expected date of entry into force of the SOLAS amendments is 1 January 2017, under the tacit acceptance procedure. Polar code requirements will apply to new ships constructed after that date. Ships constructed before 1 January 2017 will be required to meet the relevant requirements of the Polar Code by the first intermediate or renewal survey, whichever occurs first, after 1 January 2018.

3. DATA DEVELOPMENT

This Section describes the primary sources of patent data and policy documents related to the environmental issues described in Section 2.2. Data on patents to be used in this project were drawn from the latest version of PATSTAT. The patent data provided for this work is in summary form, pending future work to develop quality metrics. Data on environmental policies affecting international shipping were developed after a survey of several sources, including international environmental agreements and limited review of European Union, United States, and other national policy actions. Recognizing that most international shipping policies derive from or lead to international agreements at the International Maritime Organization (IMO), a detailed investigation was conducted into policy development at IMO. IMO working documents over two decades of effort related to environmental agreements at IMO were reviewed and catalogued. The international policy data for this work represents its first use in the context of quantitative research into innovation and policy relationships.

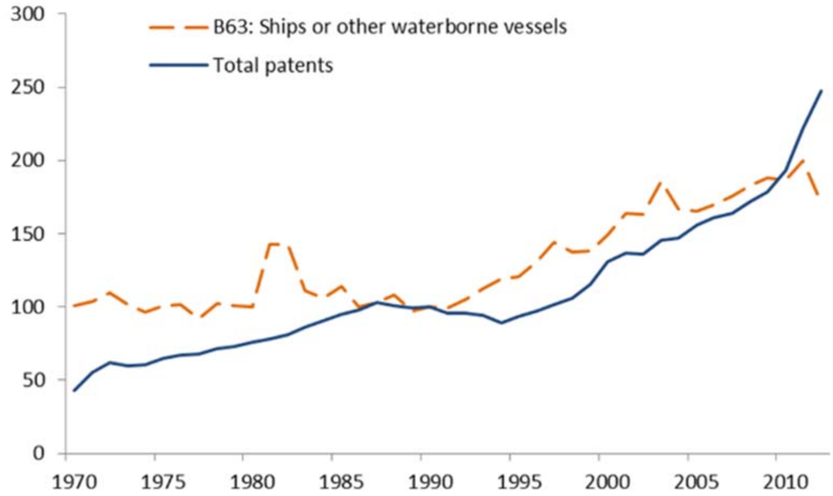
Data developed to describe patent activity (Section 3.1) and policy activity (Section 3.2) are summarized in Table 1. The time series for patent data is longer than for available policy documents, so analyses in Section 4 trim the data to common time periods, also shown in Table 1. Patent data suggest that the recent decades have seen substantial innovation for environmental performance, compared with overall ship and waterborne patent activity, where the period 1997-2012 accounts for about 40% of ship technology patents. Table 1 also summarizes environmental policy data, in terms of policy decisions and working documents leading to policy decisions. To be clear, the IMO document repository (IMODocs) contain policy decision documents reflected in the IEA Database, but also include the numerous delegate submittals to committees leading up to policymaking.

3.1 Patent data characterization

Patent data was extracted from the Worldwide Statistical Patent Database, maintained by the EPO, for all available years inclusive of 1900 to 2013 (Daniel et al., 2015). These patent data are not limited to European patents but include patents filed at IP offices in other countries, resulting in more than 90 million patent documents worldwide. EPO patent data have been used previously by OECD researchers and others, including other evidence-based studies of the relationship between different policy actions and technological innovation. (See, for example, OECD 2012).

Figure 2 shows the trends of total patents and patents related to ships or other waterborne vessels since 1970. All data in this Figure are indexed to 1990 (1990 = 100). The results highlight that patenting, is increasing at a slower pace in the maritime industry than in the economy more generally. As a relatively mature sector, this is hardly surprising.

Figure 2. Index of patent activities: Total patents vs. patents related to ships or other waterborne vessels 1990 = 100



Source: OECD based on Worldwide Statistical Patent Database at https://www.epo.org/index.html

In order to develop patent counts for environmental technologies the Cooperative Patent Classification (CPC) code classifications were reviewed, and within that subsets of patent documents were identified for the following environmental issues:

a) Air pollution technologies;
b) Climate change technologies;
c) Emissions and energy technologies, defined here as the combination of (a) and (b);
d) Ballast water technologies;
e) Oil spill and recovery technologies.

Table 1. Summary of documents reviewed by key environmental issue (both patent data and IMO policy documents)

Data type	Ships B63 patents	Air pollution	Climate Change	Emissions (inclusive)	Ballast Water Treatment	Oil Spill Prevention and Recovery	Combined Issues
Patents (1961-2012)	80,843	323	5432	5755	3087	3003	11,845
Patents during (1997-2012)	33,984	**217**	**3334**	**3551**	**1938**	**1879**	**7368**
Percent	*42%*	*67%*	*61%*	*62%*	*63%*	*63%*	*62%*
IMO documents in study period (1997-2012)							
IMO Environmental Policies (1954-2015)		9	0	9	1	34	53
IMO Environmental Policies (1998-2012)		9	0	9	1	16	35
All IMODocs: 6961 (Selected 2520)[1]		**508**	**612**	**1120**	**828**	**276**	**2224**
Percent by topic		*23%*	*28%*	*50%*	*37%*	*12%*	*100%*

Note: Emissions issues represent the combination of air pollution and climate change issues. Percent values may not add to 100% due to rounding.

Sources: Worldwide Statistical Patent Database at https://www.epo.org/index.html; IMO documents at https://webaccounts.imo.org/

Overall, some 80 000 patents have been identified since 1961 (Daniel et al., 2015). Of these patents, approximately 25% are identified as being related to emissions control, oil spill prevention and recovery, or ballast water treatment**.** However, there has been a change over time. Figure 3 shows the share since 1997 time, rising from less than 15% to over 30% recently. In the mid-200s there was a significant break with environmental patents becoming much more prevalent, suggesting a "bending" in the trajectory of innovation towards greener ships (Figure 3).

Figure 3. Share of environmental ship patents of total ship patents, 1997 – 2012

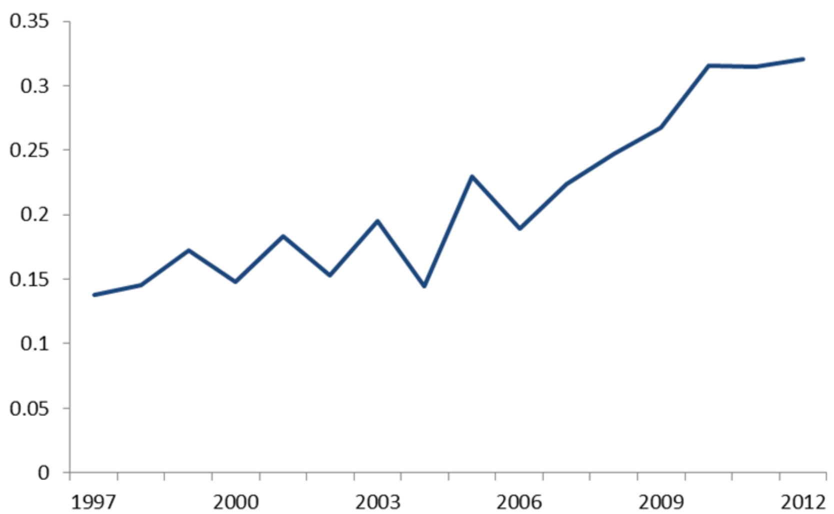
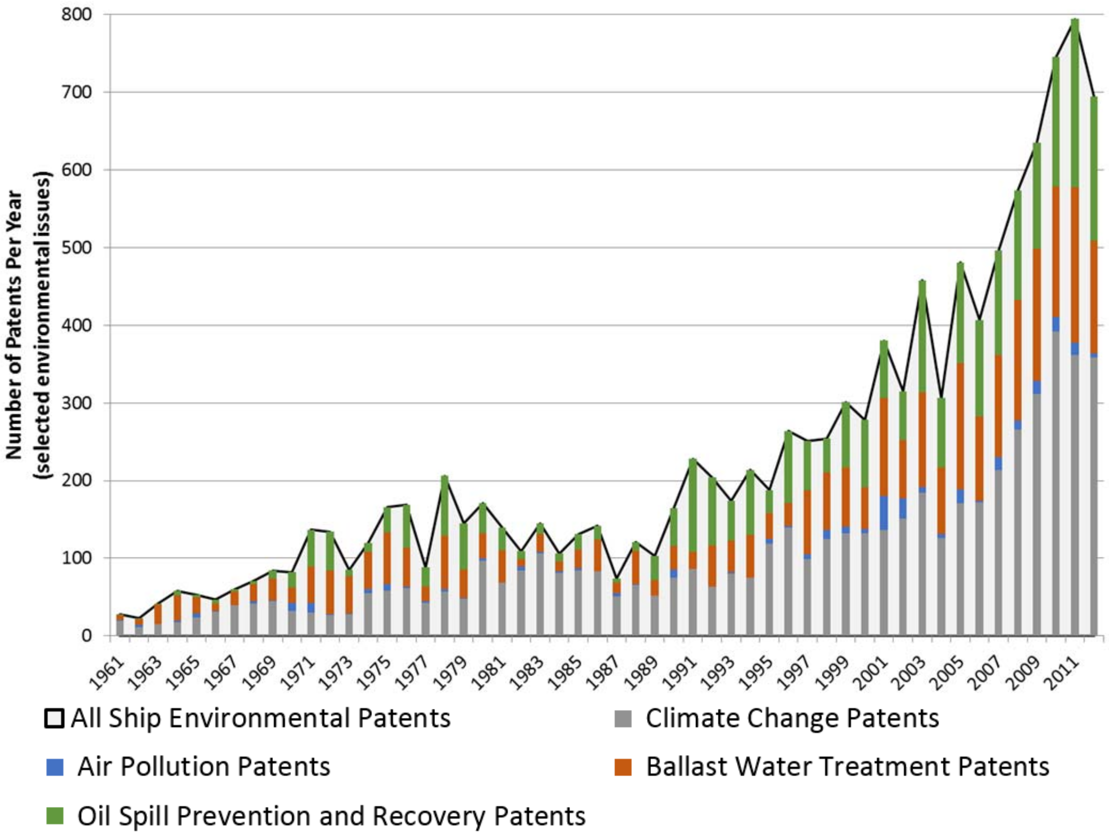


Figure 4 illustrates the number of patents since 1961 broken down by environmental issue. Figure 6 breaks this out into the different fields to allow for comparison with the trend in patenting for the sector overall. All data are indexed to 1990 (1990 = 100). One can observe the relative similarities or differences in slope trends for a) marine-related climate change patents v. ship or waterborne patents; b) ballast water patents v. ship or waterborne patents; c) oil spill recovery v. ship or waterborne patents; and d) air pollution v. ship or waterborne patents.

Much less patent activity is observed for air pollution technologies, compared with other ship environmental technologies. By looking at the yearly activity in the data from Section 3.1, air pollution patents number are on the order of 1 to 20 per year (average 6 per year over time period, with max 43 in 2001). In contrast, climate change patents are much more numerous (about half of all environmental patents per year, averaging over the time period), and clearly increasing over the period of 1961-2012. Ballast water and oil spill prevention and recovery patents account for about 28% and 22% of the annual average environmental patent activity, respectively.

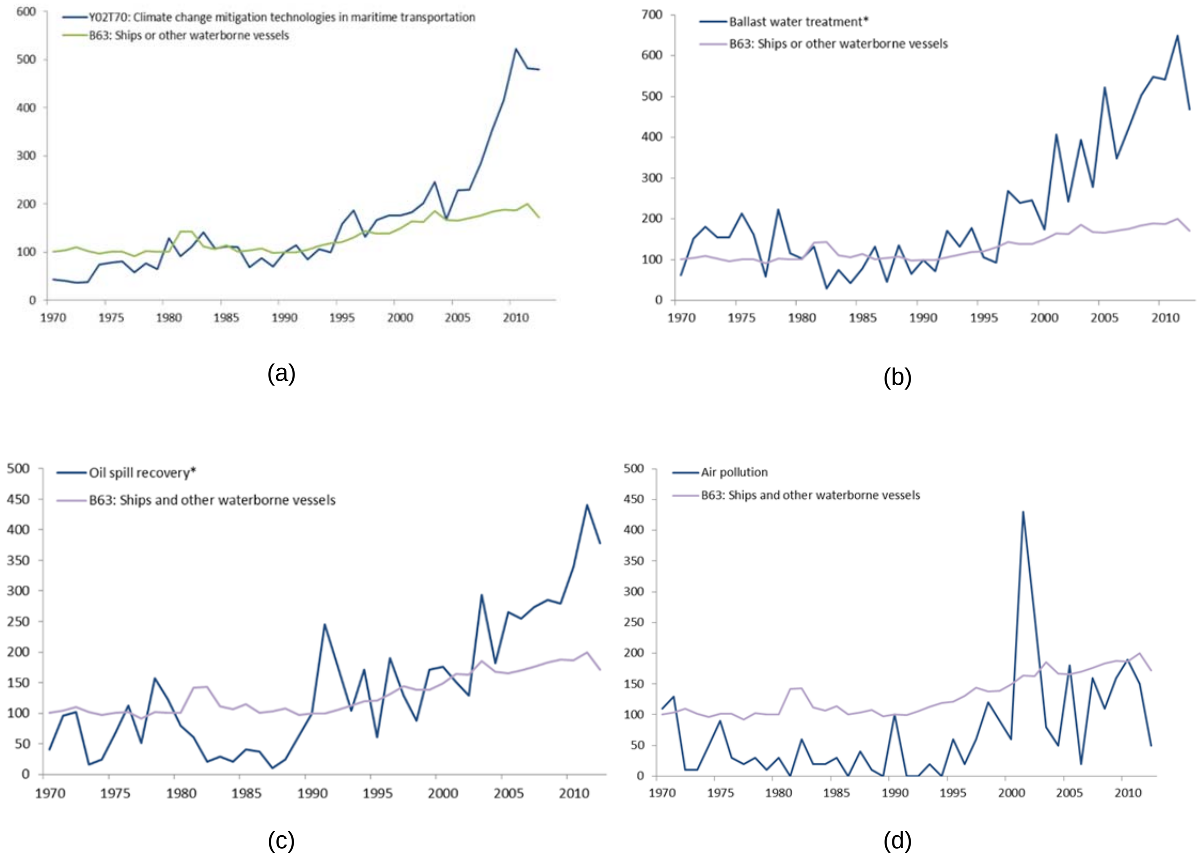
Figure 4. Time series of environmental patent activity in shipbuilding (1961-2013)



Source: IMO documents at https://webaccounts.imo.org/

In summary, there exists strongly positive (i.e., increasing) trends in patent data over time for patents relating to combustion emissions, particularly climate and energy related patents, and for ballast water and oil spill technology patents. In comparison with all ship and waterborne technology patents, climate and energy related patents exhibit the strongest trend relationship over time.

Figure 5. Indexed patent trends (1990 = 100)
for various ship and waterborne technologies (1970-2012).



Note: Category CPC =B63 for patents on ships and waterborne vessels and related equipment; b) OECD extractions from European Patent Office (2015).

Note: Category CPC = Y02T70 for patents for climate change mitigation technologies related to maritime or waterways transport; CPC =B63 for patents on ships and waterborne vessels and related equipment; c) OECD extractions from European Patent Office (2015).

Note: *Query for ballast water treatment CPC = ((B01D OR B01F OR C02F) AND B63) OR B63J4 OR B63B13/00 OR B63B43/08 OR B63B59/00 OR B63J4; CPC =B63 for patents on ships and waterborne vessels and related equipment; e) OECD extractions from European Patent Office (2015).

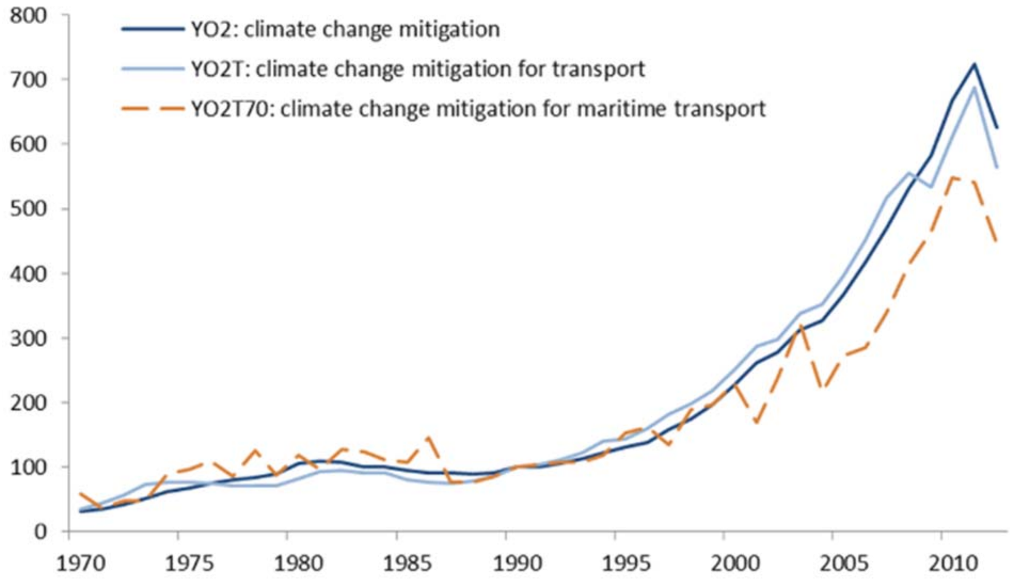
Note: *Query for oil spill recovery CPC = (E02B15 OR B01D17/00 OR B01D17/02 OR C02F1 OR C09K3/32 OR B63B25/082 OR B63B35/32 OR B63B27/30 OR B63B17/0036) AND B63; and f) OECD extractions from European Patent Office (2015).

Note: *Query for air pollution CPC = B63 AND (B01D53 OR B01J23 OR F01M13 OR F02B47 OR F02D21 OR F02M2 OR G01M15 OR F02D4 OR F02M3 OR B01D53 OR F23G7 OR F23J15 OR F27B1 OR C21B7 OR C21C5 OR F23B80 OR F23C9 OR F23C10).

Sources: OECD extractions from European Patent Office (2015) at https://www.epo.org/index.html.

In order to get a better understanding of patenting activity for climate change mitigation in shipping we can also compare the trends with two other counterfactuals: i) climate change mitigation innovation in general; and, ii) climate change mitigation innovation in transport. While the three trend together, the rate of increase in recent years is slightly lower for maritime transport than for transport in general and climate change mitigation in general. (See Figure 6.)

Figure 6. Indexed patent trends (1990 = 100) for various ship and waterborne technologies (1970-2012).

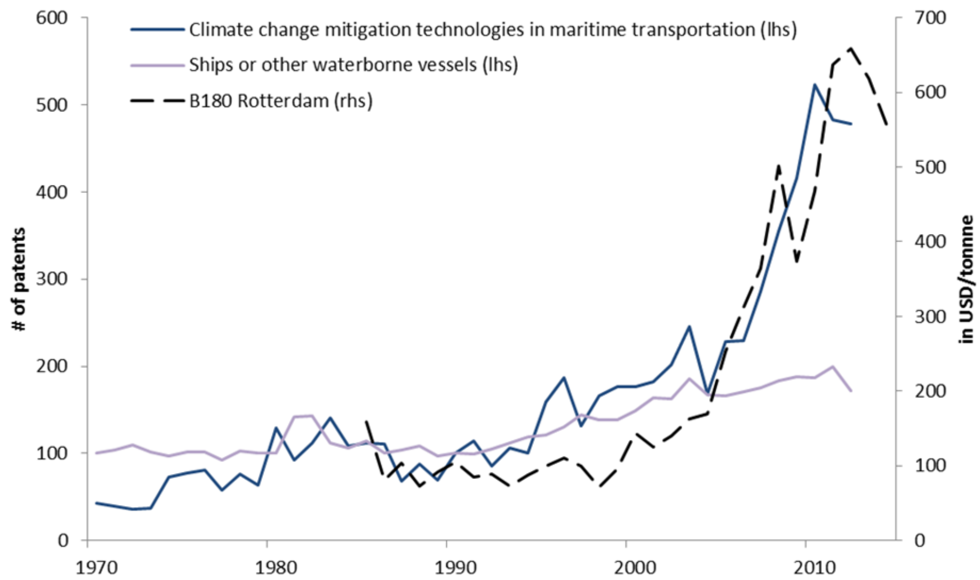


Note: Category CPC = Y02 for technologies or applications for mitigation or adaptation against climate change; CPC = Y02T for climate change mitigation technologies related to transportation; CPC = Y02T70 for patents for climate change mitigation technologies related to maritime or waterways transport.

Source: OECD extractions from European Patent Office (2015) at https://www.epo.org/index.html.

What is driving this innovation? As a first step, Figure 7 presents the above on trends for marine-related climate change patents and compares it with marine fuel (bunker) price. The correlation is very high. Significantly, the figure also shows that it is unrelated to the trend in ship and waterborne patents more generally. This provides indirect evidence for the benefits of using market-based instruments and other measures which affect relative prices to address climate change.

Figure 7. Patent count trends for climate change mitigation and bunker fuel prices (1970-2012).



Sources: OECD extractions from European Patent Office (2015) at https://www.epo.org/index.html; OECD.Stat at http://stats.oecd.org/ for Bunker fuel prices; Note: CPC on double hull: B63B3/20.

3.2 IMO documents characterization

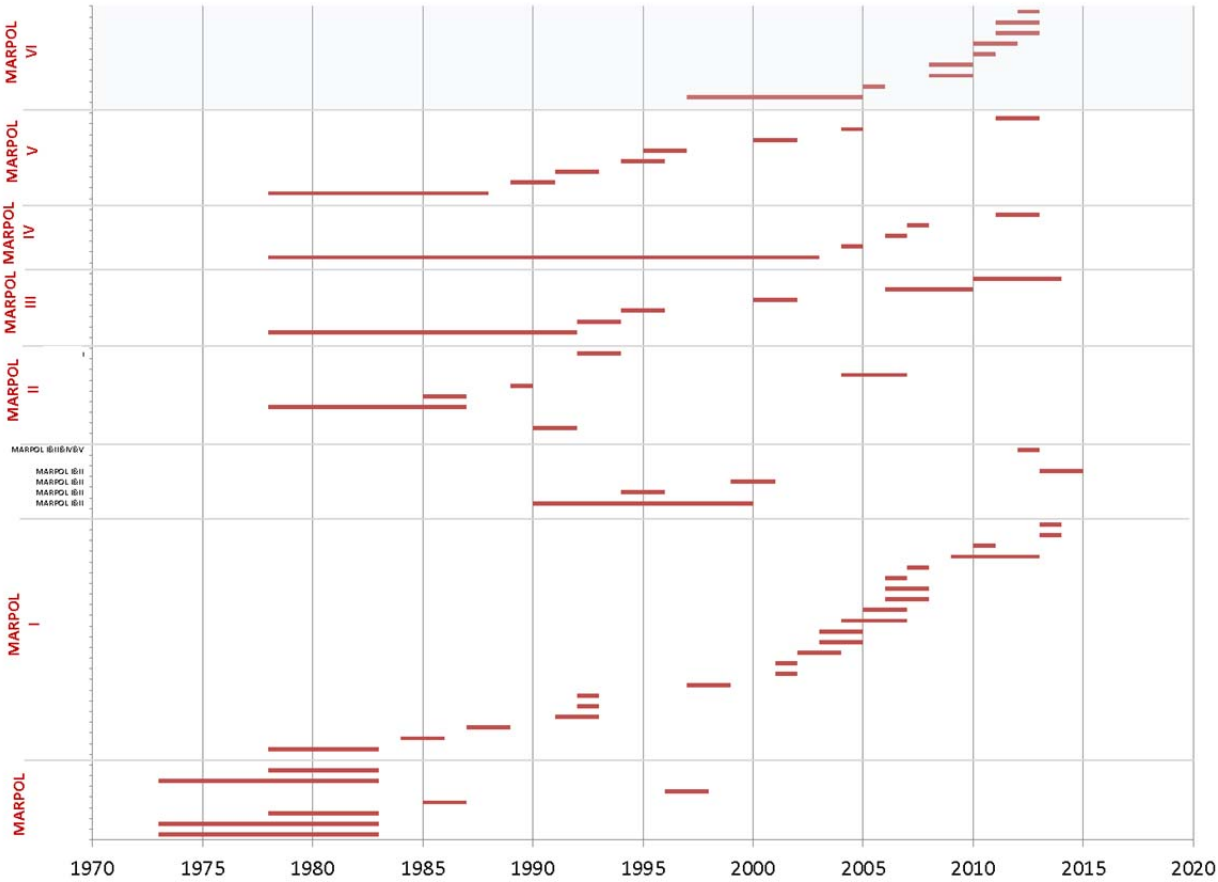
As illustrated in Table 1 and Figure 1, some 97 international environmental agreements (including amendments) were identified since 1954, with 53 related to the environmental issues addressed here. One challenge with IMO decision documents, spanning decades, includes their sparse occurrence in relation to patent activity. A second challenge is the time from introduction to entry-into-force, which can be related to both technological innovation timing and policy conditions affecting the ratification process at IMO (i.e. reverse causality issues). Figure 8 illustrates the time from date of agreement to entry into force for major agreements and amendments under the IMO MARPOL Annexes I through VI.

Additionally, these policies often prescribe an implementation schedule that occurs in the future of the date of the agreement and/or prescribes phased implementation that may occur over a decade or more. For example, the most restrictive air pollution requirements prescribed for marine fuels and/or after-treatment will become effective in either 2020 or 2025, depending on an IMO-sponsored fuel availability study to be delivered by autumn 2016 at the Marine Environment Protection Committee Session 70. Another example is the Ballast Water Convention, adopted by IMO in 2004 awaits ratification, requiring 30 States, representing 35% of world merchant shipping tonnage; as of August 2015, the Convention is ratified by 44 states, representing 32.86% of world tonnage.[ix]

The long periods from adoption to ratification and entry into force have yielded international agreements that prescribe compliance dates for international shipping that can precede the entry-into-force date. MARPOL Annex VI was originally adopted in 1997, but entered into force in 2005 (more stringent revisions adopted in October 2008 and entered into force in July 2010), and imposed operational compliance requirements on NOx emissions for ships built before 2000 be met by May 2005 (International Maritime Organization, 2008). The Ballast Water Management (BWM) Convention was adopted after 14 years of negotiations in February 2004, and is in the process of ratification. This agreement will impose specific requirements and timelines on vessels built in years prior to the entry into force date. Ships built in milestone years 2009, 2012, for example, will need to achieve performance standards by 2014 and 2016, respectively, even if the Convention enters into force after these dates (International Maritime Organization, 2004). This effectively provides a more certain signal to the shipping industry that all vessels built after a date certain would need to meet standards even if entry-into-force occurred afterward.

Figure 8 may provide interesting opportunities to investigate why initial adoption and ratification requires more time, typically, than subsequent amendments. For example, one can observe qualitatively that patent activity timing for double hull vessels follows major milestones in international environmental agreements under MARPOL I & II (Figure 8). Nonetheless, initial environmental standards achieved by consensus may be less constraining on existing practices such that innovators receive a weaker signal promoting technological change. However, that research would extend the research conducted here and is described in Section 6 under recommended future work.

Figure 8. Major MARPOL policy decisions, where red bar represents time from diplomatic agreement to entry into force.



Source: IMO documents at https://webaccounts.imo.org/

In order to perform better exploratory analyses of patent relationships with policy making, we used the abundant working documents that underpin these policy milestones. The IMO committees and decision bodies make available through a website called IMODocs a series of reports, delegate position papers for member nations and participating non-governmental organizations, working documents prior to decisions, decision documents, and other publications. Hereby, sales publications are not included. IMODocs is the IMO document repository: i) All IMO documents and reports; ii) Assembly resolutions; iii) All Council documents; iv) All Conference documents; and v) All Circulars and Circular Letters. IMODocs time series currently includes documents from 1998 to 2015 (current year not yet complete).

Policy documents used by delegates to the IMO include an indexed series of formal submissions by the Secretariat staff, and chairs or coordinators of IMO committees, sub-committees, correspondence groups, and working groups that are formed to address specific or general business of the IMO. For this analysis, a review of all IMO documents identified the following committee records that contain discussions related to technology-policy decisions about shipping and environmental performance. This primarily included meetings held regularly by:

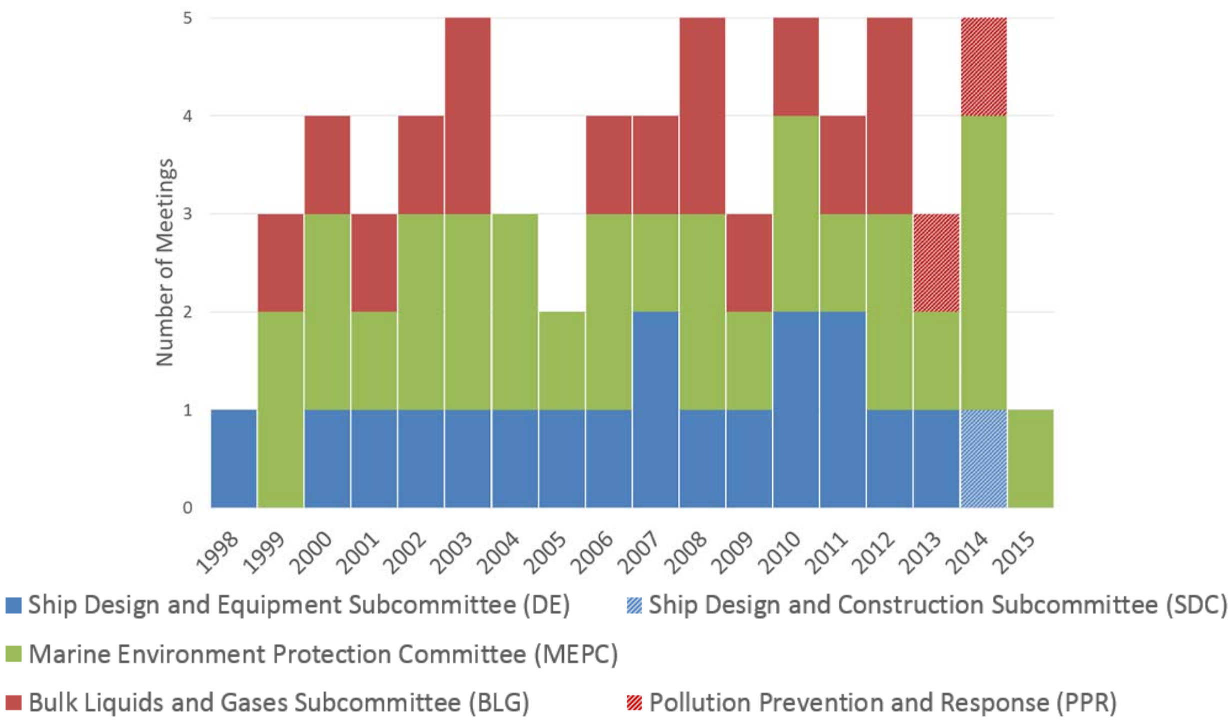
i. Marine Environment Protection Committee (MEPC) meetings 43 through 68 (January 1998 - May 2015);

ii. Subcommittee DE, meetings 42 through 57 (December 1998 through March 2013), which was renamed as Subcommittee on Ship Design and Construction (SDC) in 2014; and

iii. Subcommittee BLG, meetings 4-17 (September 1998 - March 2012), which was renamed Subcommittee on Pollution Prevention and Response (PPR) and held meetings in August 2013 and July 2014.

Figure 9 illustrates the time series of meetings of these committees, revealing that the combined number of working meetings per year results in some "oscillating" patterns where meetings per year vary between 2-3 and 4-5 between the years 1999-2014. During these meetings, the number of documents submitted by delegates and/or the IMO Secretariat (including reports by chairs of correspondence groups, drafting groups, etc.) vary according to the number of issues on each meeting agenda and according to the intensity of interest among member delegations (states and non-governmental observing groups).

Figure 9. Time series of IMO meetings addressing environmental issues in shipping (IMODocs, 1998-2015)



Source: IMO documents at https://webaccounts.imo.org/

Table 2 presents the time-series summary of IMO policy documents by environmental topic for the years 1998-2015, including the four environmental issues matched to the patent data, along with hull fouling, noise, polar, and other topics. It helps to explain the oscillating time series in policy documents, as it reveals that sequencing of meetings is not uniform year by year. The MEPC often meets on a schedule that includes two meetings nearly every other year, the subcommittees on Bulk Liquids and Gases (BLG) and Ship Design and Equipment (DE) have occasionally scheduled more than one meeting in a given year. This illustration also includes the more recent transition of BLG to the newly formed subcommittee on Pollution Prevention and Response (PPR), and the transition of DE to the newly formed subcommittee on Ship Design and Construction (SDC).[x]

Table 2. Summary of IMO documents catalogued by environmental topic

Year	Air pollution	Ballast water	Climate change	Hull fouling	Noise	Oil pollution	Other	Polar	Total by year
1998	4	3						2	9
1999		23				22			45
2000	9	20	3	10		30	26	8	106
2001	2	20	4	20		11	2	1	60
2002	7	59	5	9		23		3	106
2003	25	48	8	5		45			131
2004	9	30	8	1		13			61
2005	28	43	3	3		5	1		83
2006	20	54	15	4		15			108
2007	48	40	8	3		13			112
2008	110	66	68	11	3	11			269
2009	11	43	59	1		19		11	144
2010	39	72	111	8	11	19		24	284
2011	37	55	64	3	6	11		27	203
2012	58	84	96	4	3	7		26	278
2013	12	40	42		1	10		30	135
2014	65	94	69	5	1	12		16	262
2015	24	34	49	1	1	10	1	4	124
Total	**508**	**828**	**612**	**88**	**26**	**276**	**30**	**152**	**2520**

Source: IMO documents at https://webaccounts.imo.org/

Table 3 summarizes these documents by submitting nation or delegate group, including summary, working, draft, and decision documents prepared the IMO Secretariat.

Table 3. Relative IMO activity on environmental policy topics by key nations or delegate groups (Source: IMODocs)

Key nation or delegate group	Air Pollution	Ballast water	Climate Change	Emissions (inclusive)	Hull fouling	Noise	Oil pollution	Other	Polar	All topics
Brazil	0%	5%	0%	0%	4%	0%	2%	7%	0%	2%
China	2%	3%	5%	3%	0%	12%	1%	0%	1%	3%
EU	13%	18%	16%	15%	11%	23%	13%	10%	17%	16%
International	11%	14%	15%	13%	30%	19%	16%	17%	19%	15%
Japan	4%	11%	9%	6%	13%	8%	4%	3%	0%	8%
Korea	2%	8%	3%	2%	0%	4%	3%	0%	0%	4%
NGO	26%	9%	23%	24%	27%	15%	16%	13%	32%	19%
Norway	6%	6%	5%	5%	1%	0%	2%	10%	5%	5%
Russia	2%	0%	1%	1%	0%	0%	2%	0%	8%	1%
Secretariat	21%	26%	19%	20%	19%	4%	34%	40%	15%	23%
South Africa	0%	1%	1%	0%	0%	0%	0%	0%	0%	0%
United States	11%	4%	4%	7%	3%	15%	8%	0%	4%	5%
	100%	100%	100%	99%	100%	100%	100%	100%	100%	100%

Note: Each column depicts the percent of total documents identified in the IMO meeting submittals associated with each topic. Shading indicates which key nation or delegate group contributed more or fewer documents under that topic.

Source: IMO documents at https://webaccounts.imo.org/

4. ANALYSIS TO EXPLORE TECHNOLOGY INNOVATION AND POLICY RELATIONSHIPS

This Section provides three types of exploratory analysis to characterize relationships between innovation and policy among environmental technologies for international shipping. In order to do so we assess the correlation between matching patent and IMO data at the level of the environmental issue concerned. Before doing so, however, we examine relationships within patent data and within policy documents across environmental issues in order to assess whether some environmental concerns are addressed jointly, whether in policy or technological terms. As discussed in Section 5 and Section 6, this work leads to insights and recommendations that can focus future analyses on the most promising areas for environmental policy drivers for innovation in shipping, using the data developed for this work.

4.1 Internal relationships among data sets

The intuition one may bring to the patent data sets is that technology innovation across important families of environmental technologies would exhibit similar trends, and high correlations. We investigate this question in two steps: comparing environmental technologies with all ship and waterborne patents, and comparing each environmental technology patent series with the combined set of environmental technology patents. We do this through use of correlation tables and data plots with confidence bands on the trends were produced.

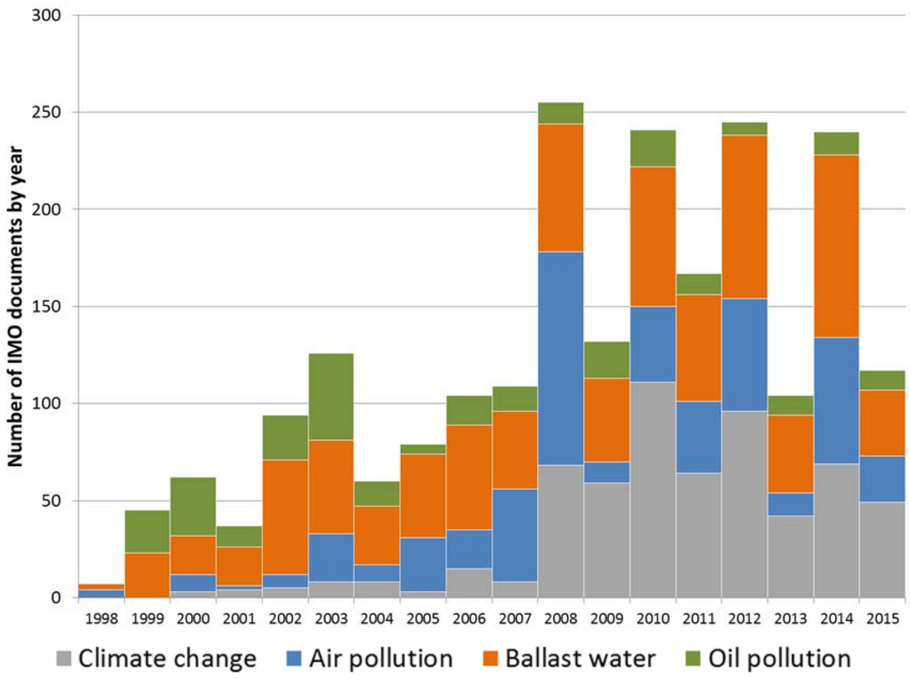
Table 4 presents a correlation Table for the internal relationships of the time series of patents (Daniel et al., 2015) trimmed to more closely match the time period for which policy documents are available (1997 – 2012). Appendix Figure 13 provides cross plots of matched-year pairs with environmental technology patents (y-axis) and all ship patents (x-axis). This is done for the aggregate environmental technology patent counts, and for emissions (combination of air pollution and climate change patents), air pollution, climate change, ballast water, and oil spill technologies. Appendix Figure 14 provides cross plots of matched-year pairs with each family of environmental technology patents (y-axis) and all environmental ship patents (x-axis); note the one-for-one graph for presentation symmetry in the upper left corner.

Innovation in environmental technologies across different areas appears to be positively correlated. However, it is interesting to note that air pollution patents are only moderately correlated with other areas, and not at all with climate change patents. Oil spill patents are highly correlated with all the other domains (except air pollution), and the same is true of ballast water treatment.

As Figure 10 and Table 4 show, we were able to match a sub-set of the IMO documents to specific technology classes represented in the patent classification system.

This suggests that some of patent-based policy comparisons may yield expected measures of innovation in shipping environmental technologies that are similar to previous research findings. However, it allows us to reject the expectation that green technology development, as measured by patent activity, to be similar to overall patent activity for ship and waterborne technologies. Section 5 will more fully discuss potential explanatory factors, including different levels of innovative activity, technology diffusion of existing inventions, or weaker policy drivers for some environmental issues related to international shipping.

Figure 10. Time series of IMO documents in environmental fields which can be matched with environmental patent classes (1998-2015)



Source: IMO documents at https://webaccounts.imo.org/

Table 4. Correlation Table among shipping patent activity (1997-2012)

	Ships B63 patents	*Air pollution patents*	*Climate Change patents*	*Emissions (inclusive) pollution patents*	*Ballast Water Treatment patents*	*Oil Spill Prevention and Recovery patents*	*Overall Ship Environmental Patents*
Ships B63 patents	1						
Air pollution patents	0.124	1					
Climate Change patents	0.770	0.014	1				
Emissions (inclusive) pollution patents	0.778	0.117	0.995	1			
Ballast Water Treatment patents	0.842	0.227	0.823	0.841	1		
Oil Spill Prevention and Recovery patents	0.834	-0.152	0.875	0.854	0.846	1	
Overall Ship Environmental Patents	0.848	0.078	0.972	0.973	0.923	0.934	1

Green: Highly correlated; Yellow: Moderately correlated; Red-orange: Weakly or negatively correlated.

Source: OECD extractions from European Patent Office (2015) at https://www.epo.org/index.html.

4.2 Exploratory model: correlated relationships

Two questions are tested in this section:

- Can we observe relationships between the matched time series of environmental patent activity for all ship and waterborne technologies and policy activity at IMO, as measured by issue-specific document counts?
- Can we observe relationships between the matched time series of patent activity for maritime environmental technologies and policy activity at IMO, as measured by issue-specific document counts?

This can be explored through analysis of matched relationships between patent counts and IMO environmental policy documents. The intuition one may bring to a cross-comparison between sets of patents and sets of policy documents is that these would be more correlated if the relationships between policy and innovation are strong. We explore this initially through use of correlation tables and data plots with confidence bands on the trends were produced.

Table 5 presents a correlation Table for simple relationships of the time series of IMO documents and patent counts for matched years. Overall IMO documents and total patent counts are relatively well correlated with 0.84 supporting the study's research question on the relationship between innovation and environmental regulation. In particular for the category on climate change mitigation the correlation is very strong with 0.94 between the submission of IMO documents and patenting activity, indicating a relationship although it is not possible to conclude on the direction of this relation.

However, each data point represents a given year. If there are lag or lead effects, which may be expected, then evidence of weak correlation for matched-year pairs does not allow us to reject the hypotheses about relationships among IMO policy development and innovation. This may require additional research to develop more complex models for investigation.

Table 5. Correlations between IMO documents and patents, by key issue

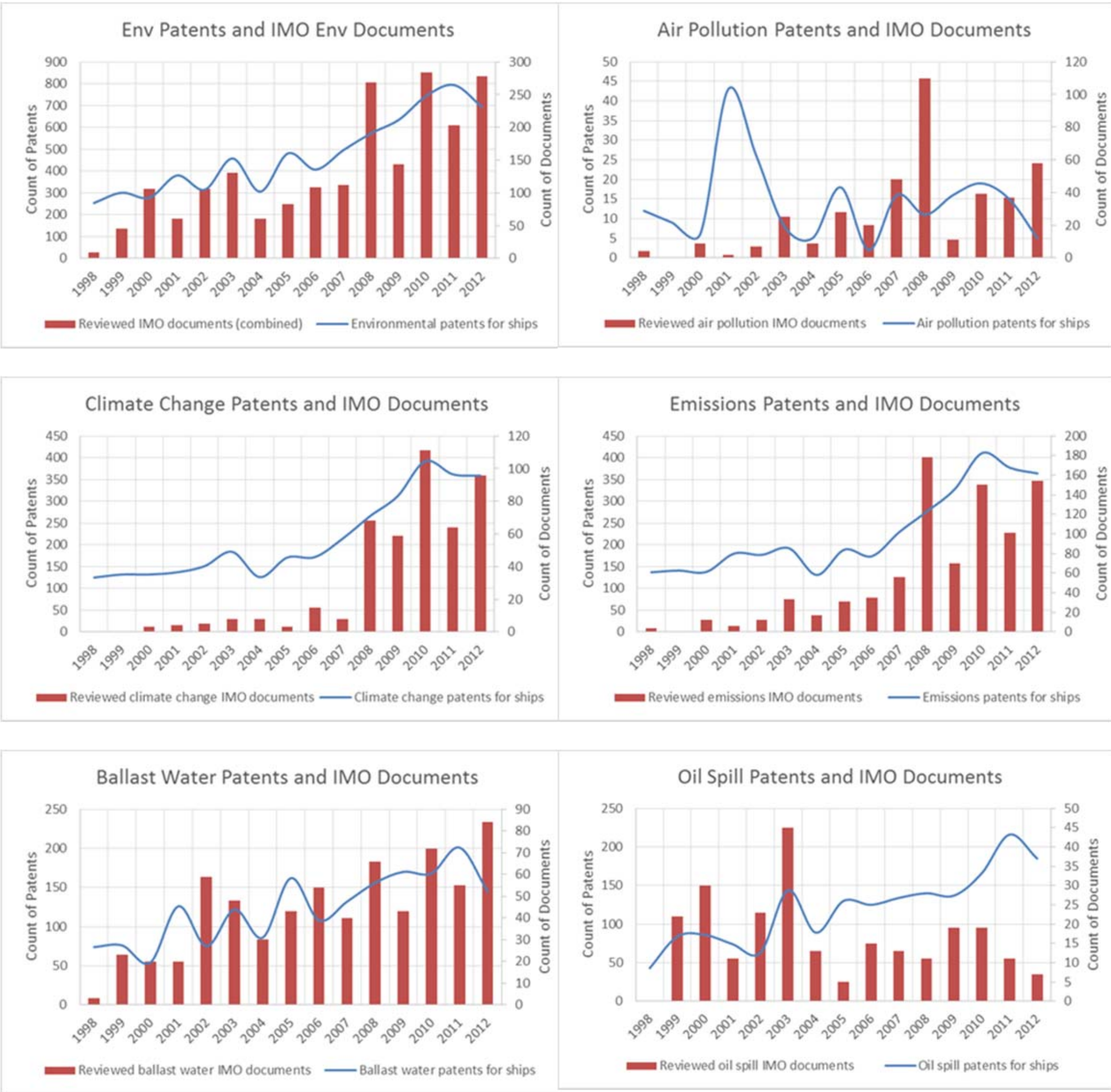
Patent data / **IMO working documents**	*Overall Ship Environmental Patents*	*Air pollution patents*	*Climate Change patents*	*Emissions pollution patents*	*Ballast Water Treatment patents*	*Oil Spill Prevention and Recovery patents*
IMO documents	0.8404					
Air pollution IMO documents		-0.2438				
Climate change IMO documents			0.9429			
Emissions IMO documents				0.8531		
Ballast water IMO Documents					0.5793	
Oil pollution IMO documents						-0.2242

Green: Highly correlated; Yellow: Moderately correlated; Red-orange: Weakly or negatively correlated.

Sources: European Patent Office at https://www.epo.org/index.html; IMO documents at https://webaccounts.imo.org/

Figure 11 shows the trends of IMO activity (i.e. number of documents) and corresponding patent activity for each environmental category. In particular for the patent categories, climate change mitigation in maritime transport and emissions levels, the graphs show a similar trend between patent activity and IMO document submissions. Since 2007/2008 there is an increase in patenting activity as well as for IMO activity for those two categories. Please note that our search for air pollution patents was more problematic as it was not possible to clearly and distinctly identify the patent codes for this category. Therefore, the link between the content of the IMO documents and patent classes for air pollution technologies is tenuous.

Figure 11. Trends of patent activity and related IMO documents, 1998 – 2012.



Sources: European Patent Office at https://www.epo.org/index.html; IMO documents at https://webaccounts.imo.org/

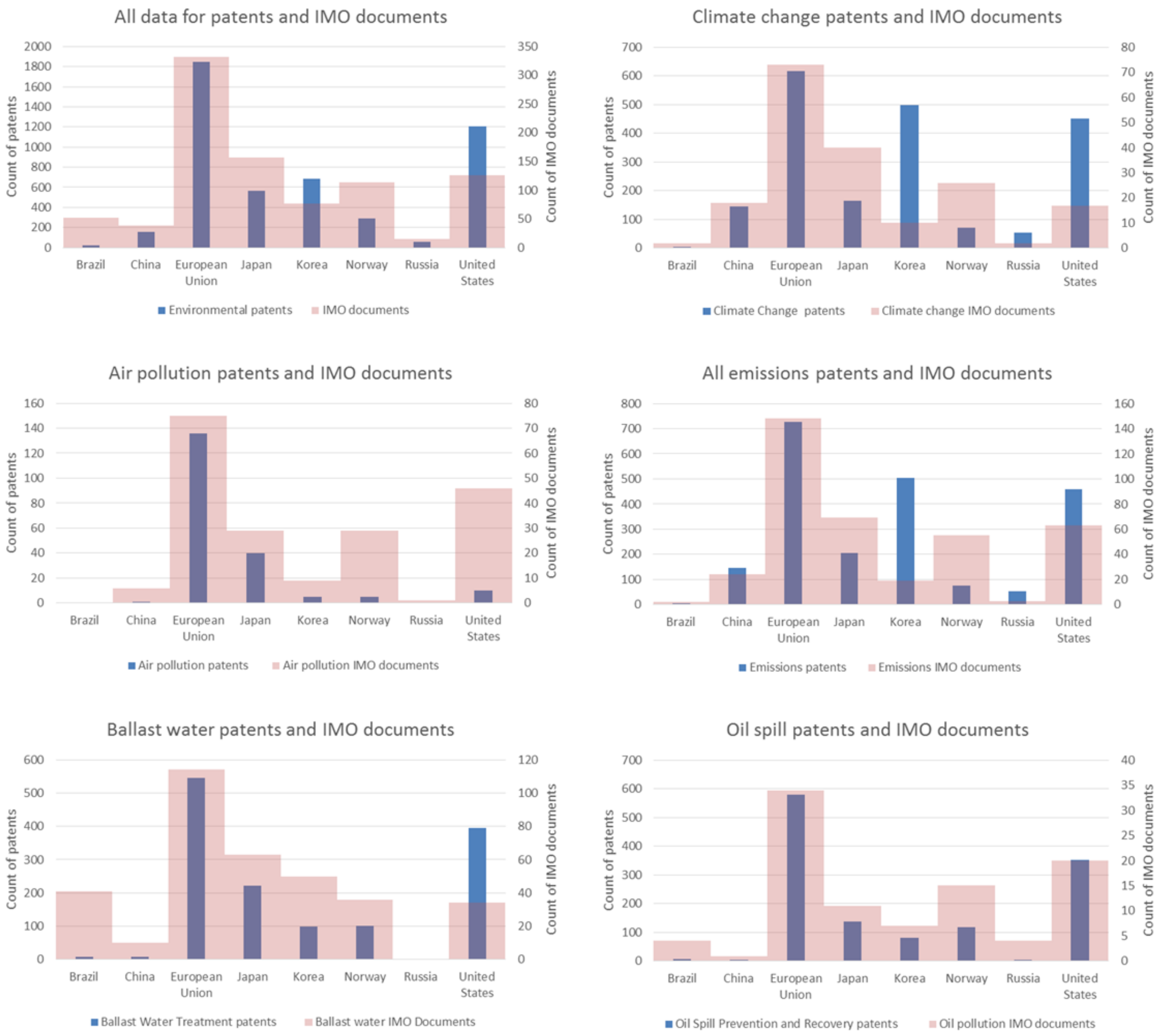
Table 6. Summary of patents and IMO documents counts between 1998-2012 for selected economies.

Nation	Brazil	China	European Union	Japan	Korea	Norwa y	Russia	United States	Sum
Environmental patents	20	159	1849	566	683	293	59	1208	4837
IMO documents	52	38	332	157	77	114	15	126	911
Air pollution patents	0	1	136	40	5	5	0	10	197
Air pollution IMO documents	0	6	75	29	9	29	1	46	195
Climate Change patents	4	146	615	165	499	70	53	450	2002
Climate change IMO documents	2	18	73	40	10	26	2	17	188
Emissions patents	4	147	726	205	504	75	53	460	2174
Emissions IMO documents	2	24	148	69	19	55	3	63	383
Ballast Water patents	9	8	545	222	99	101	1	396	1381
Ballast water IMO Documents	41	10	114	63	50	36	0	34	348
Oil pollution patents	7	5	578	139	80	117	5	352	1283
Oil pollution IMO documents	4	1	34	11	7	15	4	20	96

Sources: European Patent Office at https://www.epo.org/index.html; IMO documents at https://webaccounts.imo.org/

As Figure 12 shows, the relationships between patenting and IMO documents vary strongly across countries. According to Table 6 and Figure 12, the EU has both high patent activity and submitted numerous IMO documents. The US involvement in patenting is generally ranked second or third (i.e. after EU and in two cases after Korea). Submission of IMO documents by the US is more frequent on air pollution while its patent activity is less frequent for air pollution. Korea is involved in patenting activity relatively more for climate change, relatively less for ballast water, oil and air pollution. Japan is involved more frequently in patenting activity for ballast water, relatively less frequently for air pollution but second ranked among the nations shown, and least frequently for climate change and oil spills. Japan is involved in policy making for ballast water, emissions (both air pollution and climate change) and for oil pollution. Norway is engaged in patenting activity across the topics, with less activity related to air pollution. Similarly, its policy involvement crosses all issues. Finally, China and Russia contributed to patent activity mostly within the climate change and emissions categories, but submitted far less IMO documents than the other economies in the panel.[xi]

Figure 12. Comparisons of ship environmental patents and IMO environmental documents by economies



Sources: European Patent Office at https://www.epo.org/index.html; IMO documents at https://webaccounts.imo.org/

5. DISCUSSION AND REFLECTION

This Section presents discussion and some reflection on each of the environmental issues for which data were developed and explored. This Section considers factors important to posing better hypotheses for testing the apparently diverse relationships among environmental issues in ‘green shipping’ and technological change. These are considered for each family of patents considered in this study, with conclusions and recommendations in Section 6.

5.1 Air pollution technologies

Regulations to control air pollution from ships may not yet be considered constraining, if compared with land-side mobile or stationary sources. Initial requirements under MARPOL VI set fuel sulphur limits to 4.5% (International Maritime Organization, 1996), providing little reduction, if any, in sulphur and practically codified the status quo, because ISO limited fuel to 5% sulphur in 1987 (Corbett and Fischbeck, 1997; ISO, 2005). The 2008 amendments to MARPOL VI established additional, more stringent emission requirements for ships that operate in designated coastal areas where air quality problems are acute, called Emission Control Areas (ECA’s). Where ECAs impose substantial reductions in fuel sulphur, the technology options are fuel switching or adoption of scrubber technologies.

Existing means may be more cost effective at achieving MARPOL VI standards, at least until future implementation of Tier III standards. Moreover, uncertainty in whether technology or fuel standards will be dominant may dull the signal for innovation. MARPOL VI will require a fuel switch to cleaner fuels, but the implementation data could be moved from 2020 to 2025 depending on the availability of compliant fuel (International Maritime Organization, 2008). The IMO Secretariat commissioned a 2015-2016 study of fuel availability (see MEPC 68/INF.11 and MEPC 68/3/3, February 2015), and study results will inform MEPC delegates in their decision to preserve the 2020 implementation date or to delay.

The prices and timing of clean fuel requirements can affect which air pollution abatement technologies are most cost-effective and when investment to adopt them makes sense for fleets. A 2015 paper evaluated technology costs and policy instruments with regard to ship compliance in ECAs (Carr and Corbett, 2015). This work showed that vessels would need to operate within an ECA for more than 4500 hours annually before retrofitting them with open-loop emissions scrubbers would become cost-effective. In other words, the policy requirements under MARPOL VI leave existing options (fuel switch) as the least-cost compliance option for most ships until the stricter global fuel sulphur limit exists.

Lastly, advance exhaust treatment such as selective catalytic reduction systems and closed loop scrubber technologies derive mainly from landside innovation, and adapted or “marinized” for technology diffusion to the fleet. System commercialization for maritime service may involve additional patent invention for ancillary requirements beyond abating air pollutant emissions, but may not advance the fundamental environmental technology innovation. These factors may explain why shipping efforts to meet emerging environmental policy for air pollution do not present similarly strong relationships to climate and energy technologies.

5.2 Energy and climate change technologies

The shipping industry is a fundamental leader in minimizing costs to facilitate global trade. In a global competitive market there are two ways to maximize profits: a) increase revenue; and b) decrease costs. Fleets employ strategies to reduce energy and fuel consumption. On a century scale, shipping shifted from sail to motor power to take advantage of the economies of scale that higher energy density propulsion offered. Waterborne commerce generally is considered an energy-conserving mode of transportation (Corbett, 2004; Corbett et al., 2010), with evidence covering the past century:

> "The switch from coal to oil was motivated by a desire to reduce costs and improve vessel performance. According to the British Admiral Fisher's remarks to Winston Churchill in 1911 (quoted in Yergin's 1991 book, The Prize, p. 155), a cargo steamer could '*save 78 per cent in fuel and gain 30 per cent in cargo space by the adoption of the internal combustion propulsion and practically get rid of stokers and engineers*' (Yergin, 1991). Essentially, the commercial sector (and soon followed by the military) converted to oil-fired boilers and oil-fuelled internal-combustion, compression-ignition engines in order to save money and achieve performance advantages."

There are a variety of technological and non-technological responses can be used to avoid fuel costs. For example, in the face of high fuel prices, short-run profit-maximizing behaviour can adopt route-specific, economically-efficient speeds, as a way to reduce fuel costs, thereby saving energy and reducing GHGs (Corbett et al., 2009). However, with regard to energy savings, there is industry evidence that technological change is a long-standing primary means of modernization. Most remarkable among these are modern marine engines and power systems:

> The "*tremendous increase in internal forces and pressures that accompanied this power rise was handled not by doubling the physical size of the engine, but through advanced materials, forging, and structural technologies. There have also been great gains in thermal efficiency, the measure of an engine's ability to get mechanical work out of the energy potential of the fuel. Efficiency has been raised from roughly 40 percent in 1975 to 50 percent today, with hybrid systems pushing 55 percent. ... New methods of fuel treatment, computerized injection and cylinder controls, and new exhaust handling technologies optimize power while lowering the pollutant content of engine emissions. And now, the last bastion of steam propulsion, the LNG carrier, is under assault from compact, attractively-priced diesels that burn a combination of oil and natural gas*" (Evangelista, 2002).

Policy attention on energy efficiency in the current decades is aligned with industry goals regarding better vessel performance, energy efficiency, and cost containment. In short, the industry faces less uncertainty about the types and timing of environmental policy, recognizing that emerging policies are performance-based improvements from a well-documented baseline. The main issue as IMO policy moves forward is whether technology constraints are imposed by the baseline(s) and target(s) of energy efficiency performance standards. There is some indication that they may be less constraining than claimed, leading to incremental change with existing technologies in combination with a degree of technological change. Marginal abatement cost curves for CO_2 reduction technologies that an additional 25-30% reduction in CO_2 is cost-effective, with a range of additional CO_2 reductions between 13% and 47% (Faber et al., 2012). Moreover, there is some evidence that market forces, namely fuel price trends, can influence energy efficiency design measures as represented by the EEDI. A 2015 paper shows that sustained increases in fuel prices in the 1980s led to improved efficiencies that were not sustained when fuel prices declined (Faber and Hoen, 2015). That work reports "design efficiency in the 1980s and 1990s was up to 10% better than in the period 1999–2008. Moreover, alternative fuels, such as LNG, may be jointly addressing air pollution and cost targets; this could imply that fuel transitions might become strong signals for technological change in shipping in the next decades. Additional research is needed as the IMO policies on EEDI and SEEMP enter into force to determine whether environmental policy for shipping among the aligned drivers is statistically significant and/or potentially technology-forcing.

5.3 Ballast water technologies

Ballast water policy development at IMO appears to present an intuitive example of technology-forcing policy, or conversely, innovation-enabled policy. This is because of the specification of technology approval processes at IMO for on-board treatment technologies that is explicit in the IMO Ballast Water Convention (IMO Secretariat, 2008). More than 120 documents submitted to the IMO MEPC and subcommittees discuss the BWT type approval process and present specific technologies for type approval to promote commercialization. None of these mentions patents, but that only suggests that newly patented technologies were not a specific requirement of the type approval process focused on certifying performance.

A summary of the evolution of the IMO policy on ballast water is provided in (Firestone and Corbett, 2005):

> "In 1991, the IMO's MEPC adopted guidelines calling for the prevention of the introduction of unwanted organisms, pathogens, and sediment from ballast water which, with slight modification, were adopted by the IMO in November 1993 (IMO, 1993). The IMO agreed to more comprehensive guidelines to control ballast water in 1997 (IMO Secretariat, 1997) and began to emphasize principles of risk minimization (McConnell, 2002). The guidelines were an important development because they set forth internationally agreed management practices and called for uniform action by states. Yet the guidelines have a number of deficiencies: they are nonbinding; rely heavily on the mid-ocean exchange of waters (and associated organisms) taken up from coastal waters in the vicinity of the port of origin for oceanic waters (so-called ballast water exchange or BWE); and provide little incentive for treatment innovation. In the 1997 resolution adopting the 1997 guidelines, the IMO acknowledged the need to complete a legally binding ballast water instrument (IMO Secretariat, 1997).

While further research would be required to confirm or modify the role of IMO environmental policy regarding ballast water treatment technologies, there are two possible conditions that may explain less significant relationships. First, the current Ballast Water Convention is not yet fully ratified and has not entered into force. This is a dubious condition with regard to innovation because by either 2014 or 2016 most ships will need to install an on-board ballast water treatment system (International Maritime Organization, 2004). Second, the performance standards under the Ballast Water Convention prescribe limits to the numbers and sizes of viable organisms per volume of discharged water (International Maritime Organization, 2004). This imposes treatment by filtration and/or active substances that may not require new patents; however, the Convention does provide regulations for prototype technologies that may continue to emerge following entry into force and after 2016.

In fact, an October 2015 court finding (United States Court of Appeals for the Second Circuit, 2015) may lend evidence to the second condition, that BWM standards are not strict enough to constrain existing technology or motivate sufficient innovation of new technology. The U.S. Environmental Protection Agency (EPA) is required under the Clean Water Act to "establish and enforce technology-based limitations on individual discharges into the country's navigable waters from point sources." "Technology based effluent limits (TBELs) are based on how effectively technology can reduce the pollutant being discharged. "Congress designed this standard to be technology-forcing, meaning [US regulations] should force agencies and permit applications to adopt technologies that achieve the greatest reductions in pollution. … The EPA's Science Advisory Board (SAB) found that while no system existed for completely sterilizing ballast water, those technologies potentially could be lethal enough to meet standards 10 times stronger than the international ones," the 2nd U.S. Circuit Court of Appeals] said in a 3-0 ruling.

United State law requires the use of Best Available Technology (BAT) for pollution sources such as invasive species discharged from ballast water. "EPA can mandate that BAT requires the use of a technology that is not currently available within a particular industry when (1) the technology is available in another industry, (2) EPA finds that the technology is transferrable from that other industry, and (3) EPA can reasonably predict that such technology will adequately treat the effluent.

The court judgment found that EPA should not have chosen "IMO Standard without adequately explaining why standards higher than the IMO Standard should not be used given available technology." The SAB identified a number of technologies that can achieve standards higher than IMO, with potential to me standards ten times more stringent than IMO Phase I standards. The US EPA is now directed by this court finding to identify technologies that can exceed the IMO standard, and adjust the US regulations accordingly (United States Court of Appeals for the Second Circuit, 2015).

5.4 Oil spill prevention and response technologies

This work may imperfectly observe innovation in oil spill technologies for two reasons. First, environmental policy action at IMO to control oil pollution was a key issue in the original development of the MARPOL convention. Therefore, some technological change would have likely preceded the window in which this project could obtain complete time series of IMO documents. Second, the patent search conducted for this project focused on oil spill recovery technologies which may fall outside the jurisdiction of IMO – focused mainly the safety and security of shipping and the prevention of marine pollution by ships. Therefore, IMO policies may not be correlated with regard to potential innovations to recover spills.

6. CONCLUSIONS

Policy actions at IMO to improve shipping performance have potential relationships with technology innovation, with some evidence that the correlation between policy efforts and patenting activity varies across environmental issues. Performance based policies that are more constraining on environmental performance may be more effective drivers of technological change. Environmental policies that are more aligned with firm motivations to reduce cost, improve fleet efficiency, or increase revenue potential, including energy-related policies that may address vessel efficiency or GHGs, represent potential drivers of innovation that are related to patent activity with statistical significance. However, regulations that mandate reporting requirements and voluntary guidelines agreed to in early international agreements may be less effective drivers of technological change. Lastly, there is some evidence that prescriptive standards defined through the IMO consensus process involving industry stakeholders may prevent worsening trends in pollution, but appear to be less stringent than land-based standards set by authorities with enforcement instruments.

IMO standards alone are not yet stringent enough to produce technology-forcing behaviour across all aspects of green ship design. In important aspects, the shipbuilding industry has become more aware of its role in environmental protection and stewardship. This is reflected in decades of policy making at IMO leading to dozens of environmental policy decision documents and international agreements. In some aspects, fleet environmental performance has improved (i.e., adopted environmental technologies and practices). Where these improvements have achieved stricter standards, innovation appears to be one of the important factors, but not the only factor, given adaptation and diffusion of existing technologies and modified operations that can often meet IMO standards. Some studies are identifying families of environmental technologies that can be considered cost-effective ways to achieve greater reductions in pollutant emissions or discharges. Existing or pending international agreements for ships often have long phase-in periods, after ratification and entry into force, that move into the future some important environmental constraints that may prove to be technology forcing.

Environmental policy at the international level may be considered potentially technology forcing in some areas, like energy efficiency and climate change. However, further work is needed to investigate better this relationship. To fully evaluate maritime environmental technology-policy in terms of innovation, therefore, one would need to interpret policy action to promote greener ships in terms of new and novel innovations, technology diffusion of innovations from other sectors, technology adaptation without novel innovations, and techno-operational changes within a sphere of existing technologies.

The data developed for this research has potential for additional study. In particular, the IMO working documents present a new and understudied resource to study long-run development of international agreements involving technology.

1. Additional data gathering needs to be done to extend the IMO working documents time series backward. By including IMO working documents that predate the MARPOL convention, a complete set of documents can represent the last four decades of international environmental agreements for shipping.
2. For selected technology families, e.g., climate change and energy efficiency, these data can be used to construct and test statistical hypotheses about the nature and strength of environmental policy making on technological change.

3. Complementary research can investigate necessary conditions for increasing environmental regulation for shipping to impose constraints on existing technology, thereby inducing technological change. This work would construct or synthesize existing economic and cost analyses, such as marginal abatement cost curves, in both a social cost context and a firm behaviour context.

4. Using environmental policies at IMO as a starting point, the nature of research into green shipping and innovation can be expanded to consider other policies, including R&D policies, financing incentives for green performance designs, etc. With regards to R&D spending in the shipbuilding industry as a driver of patenting activity, despite a similar trend between both factors (Appendix, Figure 17), further work is needed to understand the efficiency of R&D support for the innovation strength in shipbuilding.

5. A broader analysis could devote its focus on other measures that are not linked with governmental policies, notably market incentives to promote green ships. In this regard, future work could summarize such measures and analyse their respective effect on promoting green ships.

6. Furthermore, future work could focus on expanding the dataset and searching for statistical models that would test for lead and lag aspects. Such aspects would be reflected in instances when regional policies or unilateral policies are being developed in advance of IMO regulation what in turn may drive national patent activity (i.e. leading patents may correlate well with later IMO documents or vice versa).

NOTES

i Milliman and Prince (1989) was one of the first papers to analyse the induced policy response to innovation, arguing that depending upon policy instrument choice causality can run in both directions, and that this has implications for the strategic behaviour of firms.

ii For example, in August 1990, the United States Oil Pollution Act Section 4115 unilaterally called for changes in ship design double-hull designs for oil tankers calling on U.S. ports after the 1989 Exxon Valdez tanker spill, motivating amendments to MARPOL Annex I that occurred at IMO over the next decade that mandated a worldwide transition to double-hull vessels or their equivalents. Ocean Studies Board, Marine Board, 1998. Double-Hull Tanker Legislation: An Assessment of the Oil Pollution Act of 1990. National Academies Press.

iii Pages 27-28 of the OECD Patent Statistics Manual Other describe other limitations to the use of patent data (OECD, 2009).

iv See Johnstone et al., 2010b for a analysis of the renewable energy sector.

v Per Article 14 (1) of MARPOL: “A State may at the time of signing, ratifying, accepting, approving or acceding to the present Convention declare that it does not accept any one or all of Annexes III, IV and V (hereinafter referred to as “Optional Annexes”) of the present Convention. Subject to the above, Parties to the Convention shall be bound by any Annex in its entirety." http://www.imo.org/en/OurWork/Environment/PollutionPrevention/Garbage/Pages/Default.aspx.

vi Source: www.imo.org; and: http://www.imo.org/en/OurWork/Environment/PollutionPrevention/AirPollution/Pages/Technical-and-Operational-Measures.aspx.

vii *Source*: http://www.imo.org/en/About/Conventions/StatusOfConventions/Documents/Summary%20of%20Status%20of%20Conventions.xls.

viii *Source*: Resolution MEPC.207(62) adopted July 2011, and MEPC.1/Circ.811, June 2013.

ix *Source*: http://www.imo.org/en/About/Conventions/StatusOfConventions/Pages/Default.aspx.

x Note that meeting documents provided electronically on the IMO documents repository are not complete for the years 1998 or 2015 (current year of this report); moreover, prior years’ data are not yet posted electronically by IMO.

xi See also Appendix Table 7.

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APPENDIX

Internal relationships: correlations within patent data

Figure 13. Relationships and confidence bands between all ship patents (B63) and ship environmental patents (1961-2012).

Figure 14. Relationships and confidence bands between all ship environmental patents and specific issue patents (1961-2012).

Internal relationships: correlations within IMO documents data

Figure 15. Relationships and confidence bands between all reviewed and issue-specific IMO documents (1998-2015).

Exploratory relationships: Correlations between all ship patent activity

Figure 16. Relationships and confidence bands between all ship patents (B63) and IMO environmental documents (1998-2012).

Relationships among national technology patents and IMO policy activity

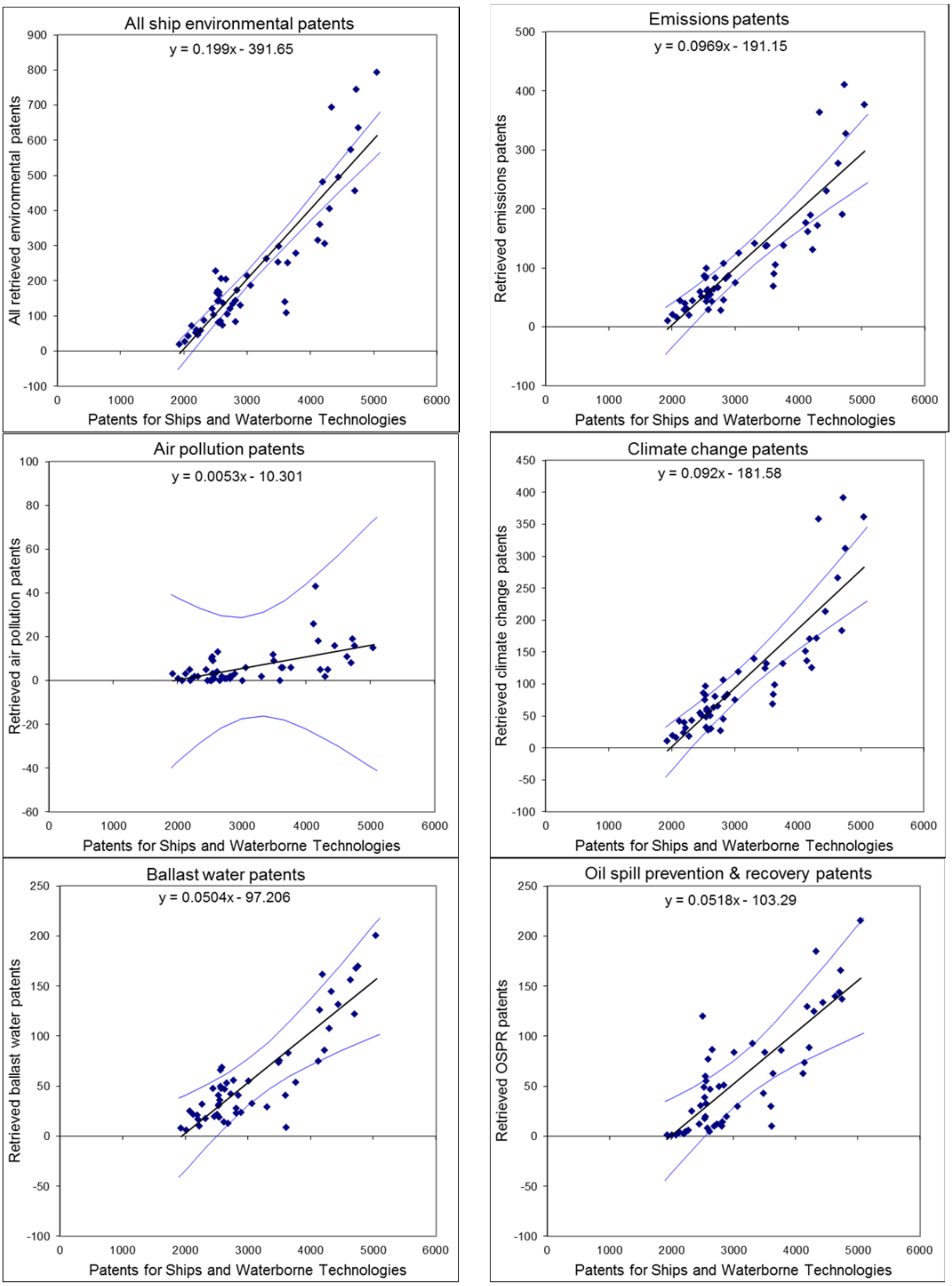
Table **7**. Summary of selected nations patent activity and IMO submissions (1998-2012).

R&D in shipbuilding

Figure 17: Total R&D expenditures in 'building of ships and boat' and patent activity.

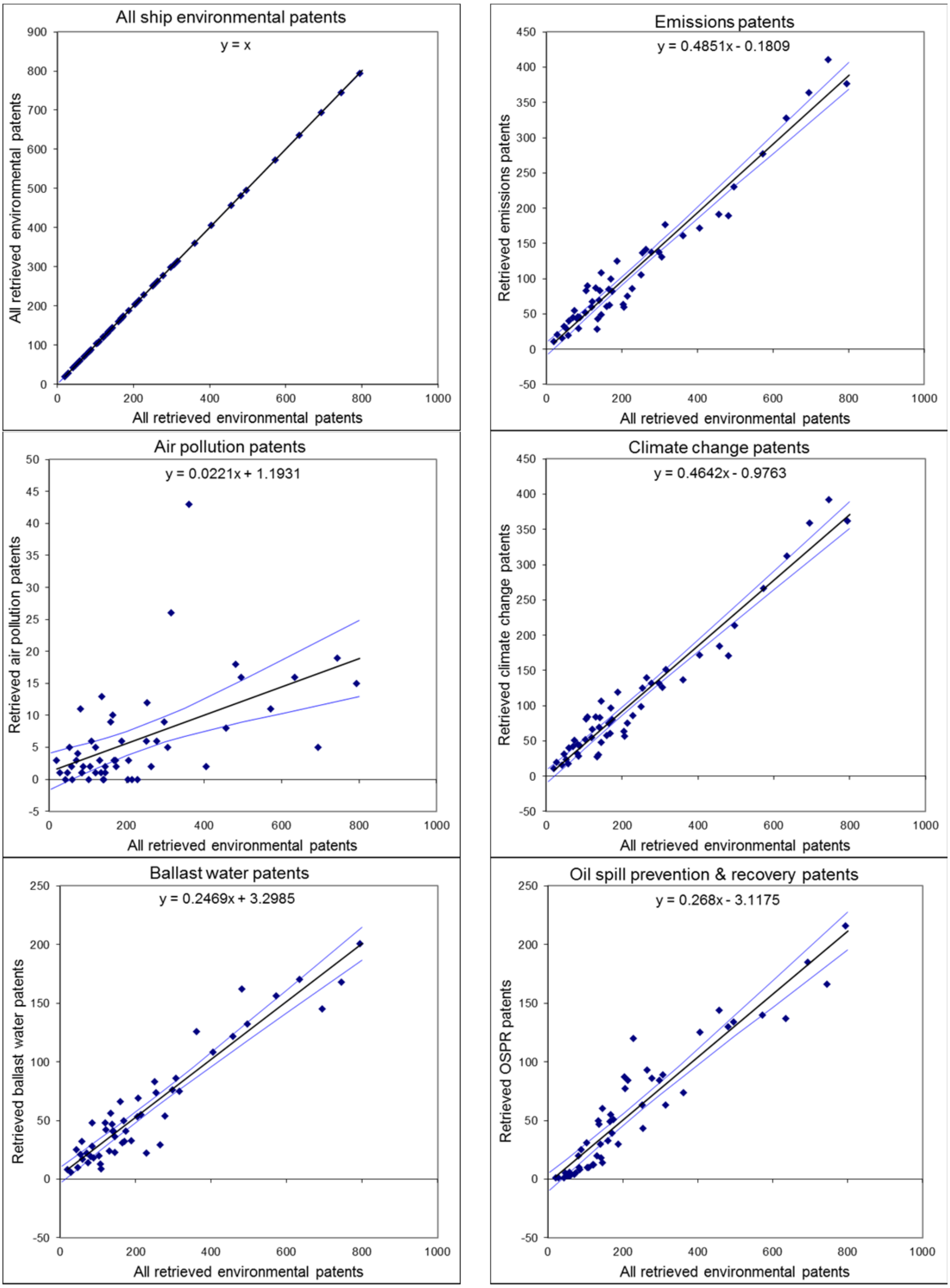
ANNEX 1. SUPPLEMENTARY FIGURES

Relationships and confidence bands between all ship patents (B63) and ship environmental patents (1961-2012)



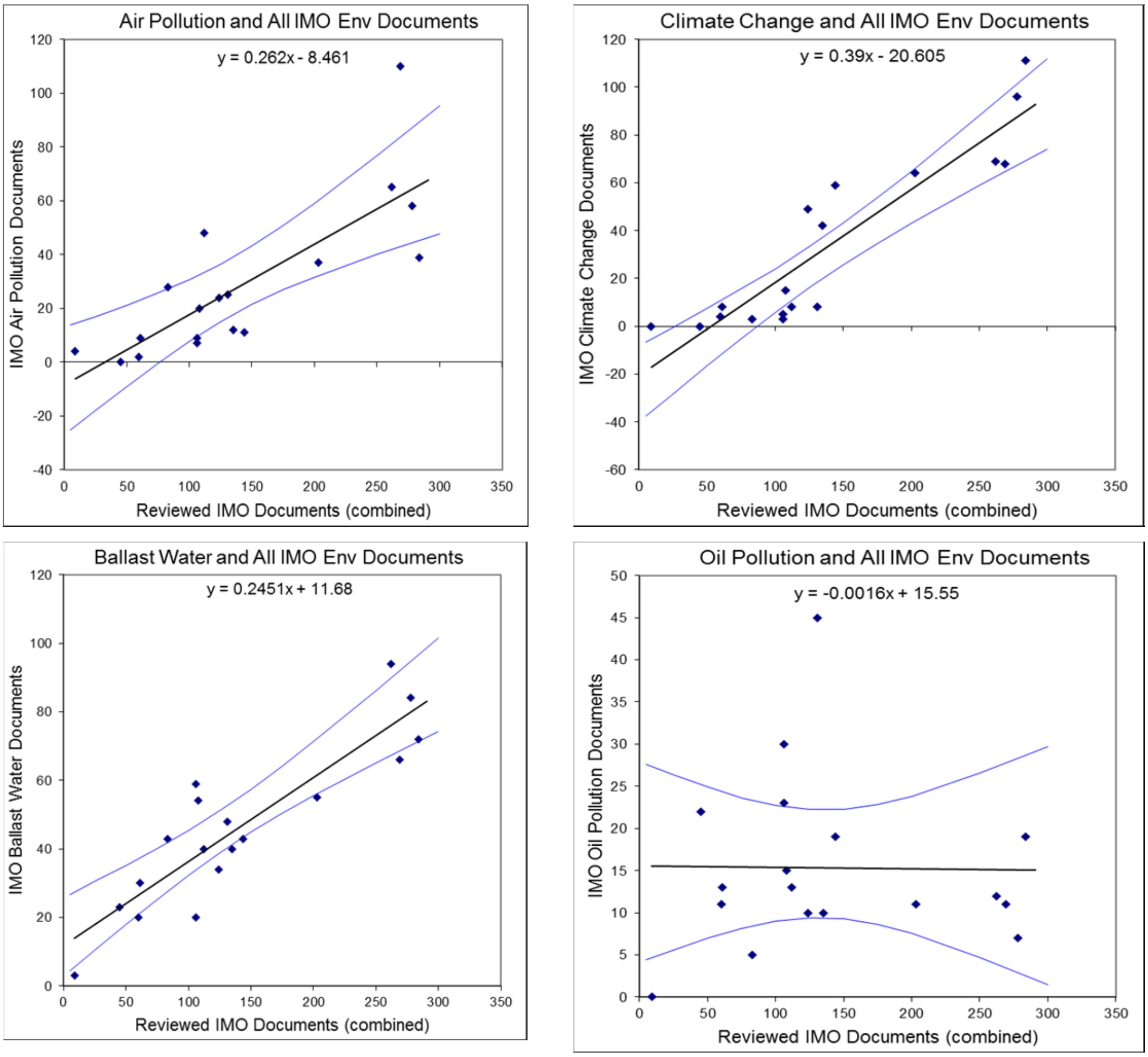
Sources: European Patent Office at https://www.epo.org/index.html; IMO documents at https://webaccounts.imo.org/

Relationships and confidence bands between all ship environmental patents and specific issue patents (1961-2012)



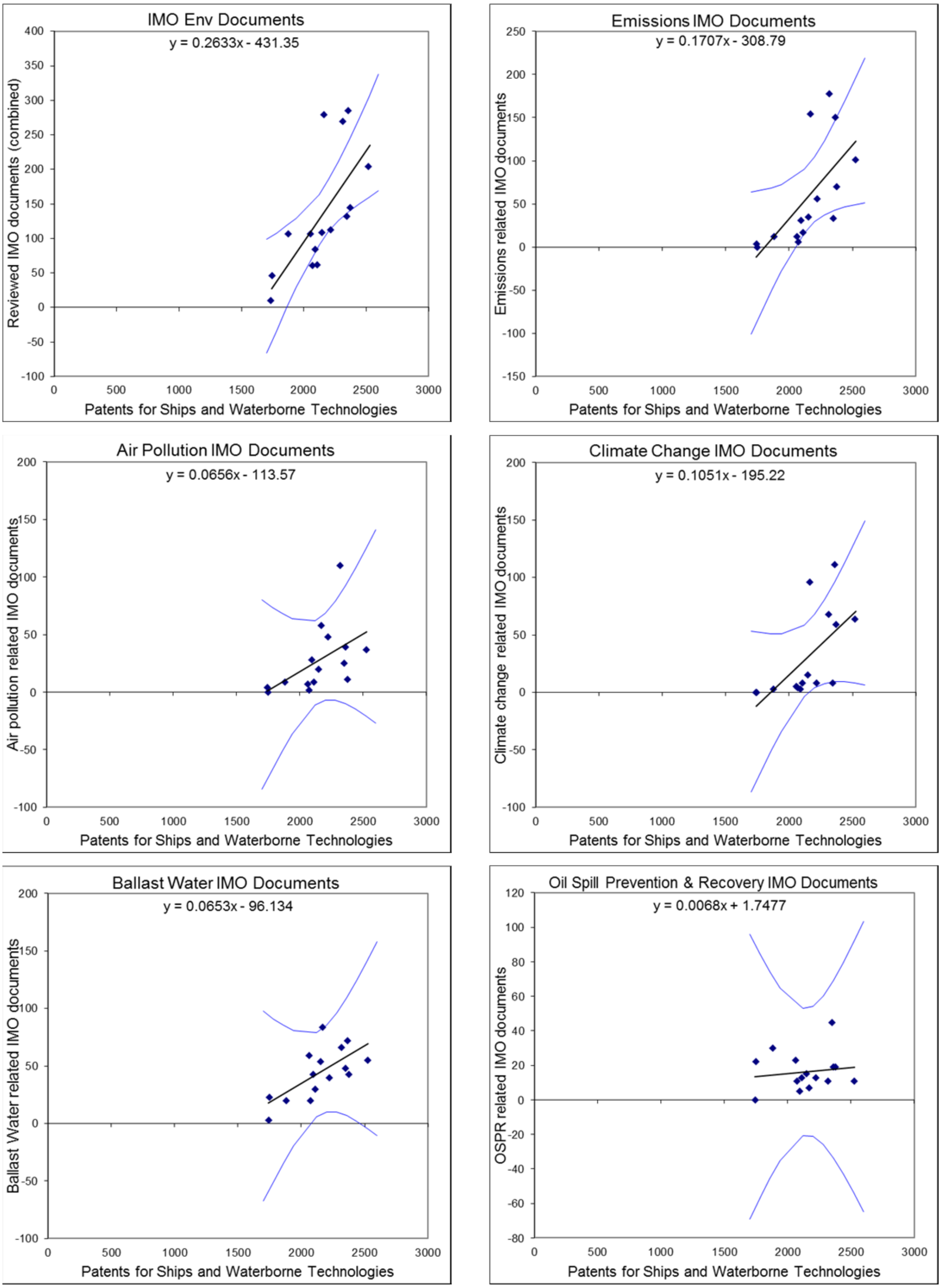
Sources: European Patent Office at https://www.epo.org/index.html; IMO documents at https://webaccounts.imo.org/

Figure 13. Relationships and confidence bands between all reviewed and issue-specific IMO documents (1998-2015)



Sources: European Patent Office at https://www.epo.org/index.html; IMO documents at https://webaccounts.imo.org/

Figure 14. Relationships and confidence bands between all ship patents (B63) and IMO environmental documents (1998-2012)



Sources: European Patent Office at https://www.epo.org/index.html; IMO documents at https://webaccounts.imo.org/

ANNEX 2. RELATIONSHIPS AMONG NATIONAL TECHNOLOGY PATENTS AND IMO POLICY ACTIVITY

National technology innovation related to shipping should be more related to overall policy activity than a single-nation engagement at IMO. Therefore, we evaluate the relationship(s) among environmental issues at IMO by nation using a given nation's patent activity and the overall IMO document list. This partly controls for the sparse engagement by nations on some IMO topics and the intermittent activity on issues nations do engage at IMO.

Table 7. Summary of selected nations patent activity and IMO submissions (1998-2012)

Nation	Environmental patents	Related IMO submissions	Correlation between patents and IMO documents	Primary patent area during study years (# in primary area)
All nations	**7117**	**1999**	**0.840**	**Climate Change (3235)**
European Union	1849	332	0.779	Climate Change (615)
United States	1208	126	-0.040	Climate Change (450)
Korea	683	77	0.851	Climate Change (499)
Japan	566	157	0.552	Ballast Water (222)
Norway	293	114	-0.059	Oil Pollution (117)
China	159	38	0.205	Climate Change (146)
Russia	59	15	0.485	Ballast Water (4)
Brazil	20	52	0.190	Ballast Water (9)

Sources: European Patent Office at https://www.epo.org/index.html; IMO documents at https://webaccounts.imo.org/

All Nations	*Overall Ship Environmental Patents*	*Air pollution patents*	*Climate Change patents*	*Emissions patents*	*Ballast Water Treatment patents*	*Oil Spill Prevention and Recovery patents*
IMO documents	0.8404	-0.1346	0.8828	0.8680	0.6477	0.7883
Air pollution IMO documents	0.5447	-0.2438	0.5236	0.4987	0.4970	0.5617
Climate change IMO documents	0.8650	-0.1410	0.9429	0.9324	0.6376	0.7198
Emissions (inclusive) IMO documents	0.8340	-0.1507	0.8696	0.8531	0.6926	0.7531
Ballast water IMO Documents	0.7390	-0.1398	0.7524	0.7371	0.5793	0.7371
Oil pollution IMO documents	-0.3219	-0.1946	-0.2620	-0.2837	-0.4324	-0.2242

Sources: European Patent Office at https://www.epo.org/index.html; IMO documents at https://webaccounts.imo.org/

Korea	*Korea Ship Environmental Patents*	*Korea Air pollution patents*	*Korea Climate Change patents*	*Korea Emissions patents*	*Korea Ballast Water Treatment patents*	*Korea Oil Spill Prevention and Recovery patents*
IMO documents	0.8512	0.0884	0.8605	0.8564	0.7500	0.7891
Air pollution IMO documents	0.4470	-0.1574	0.4755	0.4682	0.3228	0.3946
Climate change IMO documents	0.9528	0.2389	0.9592	0.9586	0.8342	0.8762
Emissions (inclusive) IMO documents	0.8387	0.1072	0.8557	0.8521	0.7120	0.7636
Ballast water IMO Documents	0.7382	0.0216	0.7271	0.7223	0.7091	0.7294
Oil pollution IMO documents	-0.3321	-0.0010	-0.3435	-0.3410	-0.3002	-0.2558
Korea IMO documents	**0.9349**	0.1294	0.9291	0.9259	0.8593	0.8938
Korea Air pollution IMO documents	-0.1347	0.4472	-0.0629	-0.0589	-0.2765	-0.4821
Korea Climate change IMO documents	0.8163	-0.4575	0.8390	0.8201	0.7785	0.6554
Korea Emissions (inclusive) IMO documents	0.4596	0.2729	0.5150	0.5179	0.2612	0.2837
Korea Ballast water IMO Documents	0.8369	-0.1457	0.7806	0.7721	0.8931	0.9395
Korea Oil pollution IMO documents	0.7389	-0.2548	0.6988	0.6842	0.8129	0.9216

Sources: European Patent Office at https://www.epo.org/index.html; IMO documents at https://webaccounts.imo.org/

European Union	*EU Ship Environmental Patents*	*EU Air pollution patents*	*EU Climate Change patents*	*EU Emissions patents*	*EU Ballast Water Treatment patents*	*EU Oil Spill Prevention and Recovery patents*
IMO documents	0.7790	-0.2382	0.8547	0.7354	0.5345	0.6819
Air pollution IMO documents	0.4271	-0.2166	0.5114	0.4365	0.2817	0.3430
Climate change IMO documents	0.8102	-0.3135	0.8494	0.6692	0.5983	0.6583
Emissions (inclusive) IMO documents	0.7477	-0.2519	0.8022	0.6812	0.5636	0.6376
Ballast water IMO Documents	0.7258	-0.1639	0.8388	0.7746	0.3098	0.7004
Oil pollution IMO documents	-0.4496	-0.1524	-0.2280	-0.2619	-0.3931	-0.4249
EU IMO documents	**0.6289**	-0.2555	0.7502	0.6222	0.4173	0.5406
EU Air pollution IMO documents	0.1583	0.0770	0.1945	0.2062	0.0157	0.1584
EU Climate change IMO documents	0.7802	-0.2791	0.7584	0.5753	0.6412	0.5851
EU Emissions (inclusive) IMO documents	0.6005	-0.2363	0.6674	0.5717	0.3933	0.5349
EU Ballast water IMO Documents	0.3408	-0.3682	0.5861	0.4233	0.1165	0.2950
EU Oil pollution IMO documents	-0.4105	-0.2187	-0.3036	-0.3816	-0.4552	-0.2609

Sources: European Patent Office at https://www.epo.org/index.html; IMO documents at https://webaccounts.imo.org/

Russia	*Russia Ship Environmental Patents*	*Russia Air pollution patents*	*Russia Climate Change patents*	*Russia Emissions patents*	*Russia Ballast Water Treatment patents*	*Russia Oil Spill Prevention and Recovery patents*
IMO documents	0.4853		0.5076	0.5076	-0.0676	0.4092
Air pollution IMO documents	0.7002		0.6995	0.6995	0.1874	0.6503
Climate change IMO documents	0.3107		0.3449	0.3449	-0.2049	0.2289
Emissions (inclusive) IMO documents	0.5893		0.6106	0.6106	-0.0058	0.4967
Ballast water IMO Documents	0.3881		0.4032	0.4032	-0.0501	0.3409
Oil pollution IMO documents	-0.5139		-0.5341	-0.5341	-0.1225	-0.3752
Russia IMO documents	**0.7680**		0.7545	0.7545		0.6892
Russia Air pollution IMO documents						
Russia Climate change IMO documents						
Russia Emissions (inclusive) IMO documents	0.4768		0.4992	0.4992	-0.0987	0.4129
Russia Ballast water IMO Documents						
Russia Oil pollution IMO documents	-0.7107		-0.7313	-0.7313		-0.5000

Sources: European Patent Office at https://www.epo.org/index.html; IMO documents at https://webaccounts.imo.org/

Japan	*Japan Ship Environmental Patents*	*Japan Air pollution patents*	*Japan Climate Change patents*	*Japan Emissions patents*	*Japan Ballast Water Treatment patents*	*Japan Oil Spill Prevention and Recovery patents*
IMO documents	0.5520	0.2464	0.6376	0.5677	0.3147	0.2904
Air pollution IMO documents	0.4934	-0.1803	0.2100	0.1154	0.5020	0.5483
Climate change IMO documents	0.6181	0.3059	0.7988	0.7153	0.3966	0.1387
Emissions (inclusive) IMO documents	0.6577	0.1844	0.6375	0.5504	0.4827	0.4010
Ballast water IMO Documents	0.4965	0.1658	0.4674	0.4120	0.2635	0.4387
Oil pollution IMO documents	-0.6143	-0.1840	-0.1798	-0.1919	-0.7259	-0.5579
Japan IMO documents	**0.2880**	0.2555	0.5510	0.5023	0.0209	0.0187
Japan Air pollution IMO documents	-0.3402	-0.2912	-0.1475	-0.2016	-0.4215	-0.0918
Japan Climate change IMO documents	0.6937	0.3864	0.8294	0.7539	0.3359	0.1777
Japan Emissions (inclusive) IMO documents	0.5086	0.2260	0.6439	0.5670	0.2765	0.2170
Japan Ballast water IMO Documents	0.0331	-0.0528	0.1892	0.1335	-0.0412	-0.0674
Japan Oil pollution IMO documents	-0.4848	-0.3812	-0.3974	-0.3938	-0.6628	-0.2774

Sources: European Patent Office at https://www.epo.org/index.html; IMO documents at https://webaccounts.imo.org/

Norway	*Norway Ship Environmental Patents*	*Norway Air pollution patents*	*Norway Climate Change patents*	*Norway Emissions patents*	*Norway Ballast Water Treatment patents*	*Norway Oil Spill Prevention and Recovery patents*
IMO documents	-0.0588	0.1496	0.4519	0.4189	-0.2826	-0.0525
Air pollution IMO documents	-0.0718	0.0785	0.0383	0.0556	-0.1111	-0.0767
Climate change IMO documents	0.1371	0.2237	0.5812	0.5495	-0.1299	0.1061
Emissions (inclusive) IMO documents	-0.0385	0.1333	0.3571	0.3356	-0.2464	0.0084
Ballast water IMO Documents	0.0127	0.0711	0.6052	0.5217	-0.2369	-0.0139
Oil pollution IMO documents	-0.2749	-0.1445	-0.0859	-0.1157	-0.2429	-0.2750
Norway IMO documents	**0.1151**	0.1519	0.2686	0.2682	-0.0142	0.1240
Norway Air pollution IMO documents	0.2796	0.2454	-0.4696	-0.2737	0.4493	0.3398
Norway Climate change IMO documents	-0.3519	-0.3563	0.1454	-0.0076	-0.5008	-0.1905
Norway Emissions (inclusive) IMO documents	0.0768	0.1093	0.1442	0.1524	-0.1067	0.2345
Norway Ballast water IMO Documents	-0.1886	-0.0964	0.3325	0.2311	-0.1952	-0.3605
Norway Oil pollution IMO documents	0.6182	0.9122	-0.0199	0.1092	0.8472	0.1140

Sources: European Patent Office at https://www.epo.org/index.html; IMO documents at https://webaccounts.imo.org/

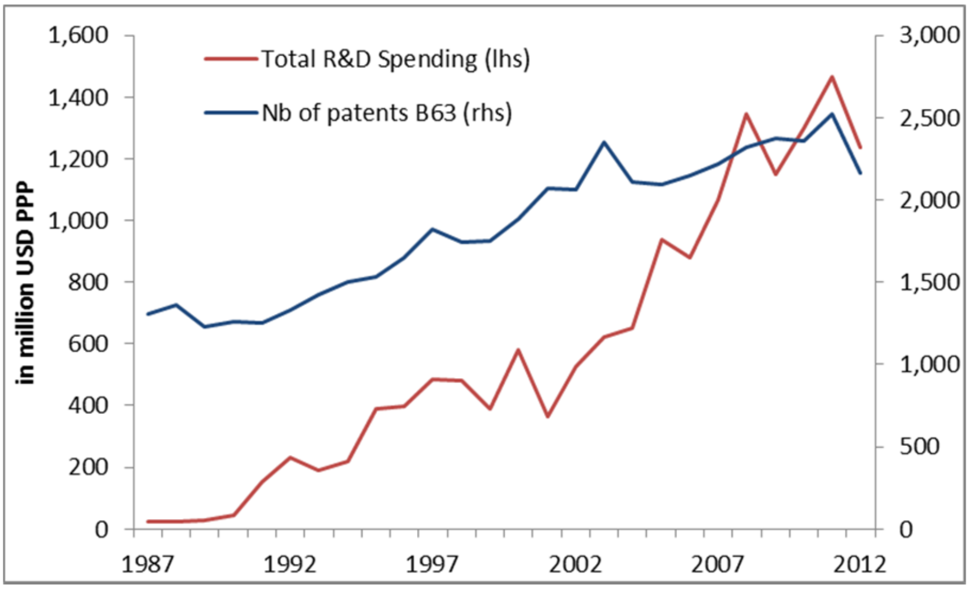
Brazil	*Brazil Ship Environmental Patents*	*Brazil Air pollution patents*	*Brazil Climate Change patents*	*Brazil Emissions patents*	*Brazil Ballast Water Treatment patents*	*Brazil Oil Spill Prevention and Recovery patents*
IMO documents	0.1900		0.5110	0.5110	0.1769	0.0184
Air pollution IMO documents	0.0324		0.2242	0.2242	0.0519	-0.0679
Climate change IMO documents	0.1534		0.5961	0.5961	0.1166	-0.0204
Emissions (inclusive) IMO documents	0.1640		0.5203	0.5203	0.1432	-0.0017
Ballast water IMO Documents	0.3694		0.4455	0.4455	0.3504	0.2212
Oil pollution IMO documents	-0.2122		-0.1847	-0.1847	-0.2343	-0.1155
Brazil IMO documents	**-0.1121**		-0.4109	-0.4109	-0.1064	0.0000
Brazil Air pollution IMO documents						
Brazil Climate change IMO documents						
Brazil Emissions (inclusive) IMO documents						
Brazil Ballast water IMO Documents	0.0097		-0.3462	-0.3462	0.0563	0.0563
Brazil Oil pollution IMO documents						

Sources: European Patent Office at https://www.epo.org/index.html; IMO documents at https://webaccounts.imo.org/

United States	*USA Ship Environmental Patents*	*USA Air pollution patents*	*USA Climate Change patents*	*USA Emissions patents*	*USA Ballast Water Treatment patents*	*USA Oil Spill Prevention and Recovery patents*
IMO documents	-0.0401	0.0171	0.3475	0.3332	-0.1838	-0.0362
Air pollution IMO documents	0.0560	0.2562	0.1469	0.1741	-0.0592	0.1431
Climate change IMO documents	-0.3537	-0.0780	0.0357	0.0217	-0.4166	-0.3228
Emissions (inclusive) IMO documents	-0.0716	0.1085	0.2679	0.2682	-0.2024	-0.0555
Ballast water IMO Documents	0.1772	0.0265	0.5771	0.5533	0.0116	0.1340
Oil pollution IMO documents	0.1213	0.0450	0.0493	0.0521	0.1449	0.0801
USA IMO documents	**-0.1160**	0.2562	0.4238	0.4311	-0.2537	-0.1808
USA Air pollution IMO documents	0.0923	0.7125	-0.1242	-0.0026	0.0040	0.2113
USA Climate change IMO documents	-0.4247	-0.1325	0.0822	0.0479	-0.4254	-0.5813
USA Emissions (inclusive) IMO documents	-0.0194	0.0727	0.3047	0.2990	-0.1349	-0.0318
USA Ballast water IMO Documents	0.0731	0.5247	0.6571	0.6808	-0.0646	-0.1089
USA Oil pollution IMO documents	-0.2659	-0.1073	-0.1242	-0.1444	-0.3182	-0.1175

Sources: European Patent Office at https://www.epo.org/index.html; IMO documents at https://webaccounts.imo.org/

ANNEX 3: TOTAL R&D EXPENDITURES IN 'BUILDING OF SHIPS AND BOAT' AND PATENT ACTIVITY



Note: Data on R&D spending should be regarded with caution as it is based on an unbalanced panel of countries and years, which is only partly comparable with the patenting data.

Sources: European Patent Office at https://www.epo.org/index.html; OECD STAN ISIC Revision 4 at http://stats.oecd.org/