DEPARTMENT OF TRANSPORT AND REGIONAL ECONOMICS

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DECISION-MAKING FOR MARITIME INNOVATION INVESTMENTS: THE SIGNIFICANCE OF COST BENEFIT AND COST EFFECTIVENESS ANALYSIS

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Abstract

Six universities from Europe, Asia and the United States participated in an evaluation of the use of innovation in the port logistics and maritime sector. Led by the BNP Paribas Fortis Chair in Transport, Logistics and Ports from the University of Antwerp, the purpose of the study was to evaluate the decision-making process and adoption of innovation using quantitative tools. This paper focuses on one of those quantitative tools, cost benefit analysis. Seventy-four separate and highly diverse innovation projects undertaken by private businesses were examined to determine if a traditional cost benefit analysis was used as part of their decision-making process. The data showed that no projects performed comprehensive cost benefit analysis, although for some projects limited cost effectiveness data were collected after the innovation was implemented. Cost benefit analysis is both complex and time consuming. It is designed for public sector decision-making, where societal costs and benefits are of concern, and where alternative policy actions are evaluated. If these innovations were implemented mainly as a result of internal decisions, use of cost benefit analysis would not be expected. The data show that 37 (50%) of the innovation projects were undertaken because of external influences, 21 (28.3%) were purely internal company decisions and 16 (21.6%) were influenced by public subsidy. Several types of innovation projects examined in this research project could be candidates for a cost benefit or cost effectiveness assessment. These are projects where environmental benefits and costs can be quantified, or where quantifiable external benefits support public investment in capital costs or in an operating subsidy. It is found that port innovation would benefit from more formalized methods of project assessment.

1 Introduction

The BNP Paribas Fortis Chair in Transport, Logistics and Ports, hosted at the University of Antwerp led an international team to examine the application of innovation among port industries involved in the (maritime) freight supply chain. Recognizing that the literature consists primarily of descriptive case studies, the goal of this research was to apply four quantitative tools to evaluate the use and adoption of innovative technologies. Those four instruments were: 1) quantitative comparative analysis, 2) Delphi method and H- analysis, 3) systems of innovative approach, and 4) cost benefit analysis. The University of Antwerp team coordinated the overall research project which included researchers from the University of Genoa, University of Lisbon, University of the Aegean, University of Southern California (USC) and Nanyang Technological University.

Data for 74 examples of port and supply chain innovation projects were collected by the research teams. Two innovation cases, the 3PL Primary Gate and the Port Single Window involved multiple analyses from different stakeholders resulting in 84 assessments. Thirty private port operators from ten countries provided data on their innovation projects. These companies represented a mix of terminal operators, stevedoring companies, transportation service providers, shippers and shipyards, along with public port authorities. The projects within the study were divided into twelve different types as listed below:

1. Innovations in dredging
2. Electronic data interchange innovation
3. IT-innovations supporting cargo flow
4. Cargo loading/unloading efficiencies
5. Innovations supporting transfer of containers
6. Reduced vehicle operating costs
7. Innovations supporting the inland waterways system
8. Monitoring innovation - vehicles & cargo
9. Space innovation
10. Inland navigation innovation within urban context
11. Equipment innovation
12. Management innovation

The USC team of researchers was responsible for the reivew of cost benefit analysis (CBA) approaches. Examination of the data set, however, revealed that formal cost benefit analyses were not undertaken in connection with any of the innovation cases. Rather, limited cost-effectiveness analysis (CEA) was undertaken for several projects, although this data was collected after the innovation project was implemented, not as a precursor to a decision to proceed with the project. The availability of public grant funds to support the innovation sometimes triggered the requirement to collect cost and cost-effectiveness data. The lack of any cost benefit data prompted the USC team to reexamine the data set to determine whether CBA or CEA could be useful tools in the port innovation decision-making process. Both cost-benefit analysis and cost-effectiveness analysis are tools for assessing whether the costs of an activity can be justified or not by its outcomes.

If maritime innovators are not using CBA and are only using CEA to a limited extent, how are private innovators making business decisions whether or not to invest in a potential innovation? Seventy four of the innovation cases that involved a private company financial investment were surveyed to determine if the investment decision was an internal one, or whether external influences, including the opportunity for public funding, factored into the investment decision. This paper categorizes the 74 innovation projects by factors that prompted innovators to undertake investments and draws conclusions about how the use of CBA or CEA analysis might be useful in port innovation decision-making.

2 Cost-benefit analysis

After defining the term 'cost benefit analysis' (CBA), this section addresses the difficulties in applying CBA followed by some recent examples of applications.

2.1.1 Defining CBA

Cost-benefit analysis (CBA) is a method to consider all costs and benefits (monetary and non-monetary, including externalities) over the life of a project. All costs and benefits are monetized, summed up over the life of the project, and adjusted to account for the time value of money. The result of this process is an estimate of net present value (NPV), the value of the stream of all benefits, net of the stream of all costs, in today's currency value. CBA requires a substantial amount of generated or inferred data. Literature regarding CBA generally focuses on the gathering of data and on the pertinence of the technique to determine the comparative ranking of alternative projects – usually those that are supported in some manner by the public sector (e.g. Boardman, 2006; Mishan and Quah, 2007; Nas, 1996). A review of the literature on applications of cost-benefit or cost-effectiveness analysis to the port sector in the broad sense (e.g. from a port supply chain perspective) reveals that few academic studies have been conducted to date on this issue (Vanelslander et al., 2015).

CBA is a decision procedure that allows decision makers to understand the trade-offs between the full costs and benefits of alternative actions. It is based on the utilitarian proposition that decision makers should maximize collective good. Its goal is to provide a neutral and comprehensive method of evaluating policy proposals, a way of aligning the diverse consequences and values implied by collective choices along a single quantitative metric (Sinden et al., 2009).

In practice, a CBA typically entails (a) the identification of a number of alternatives to address a business or policy issue; (b) the quantification and monetization of the expected stream of costs and benefits of each alternative over its lifetime; (c) the estimation of the Net Present Value (NPV) of each alternative. NPV accounts for the opportunity cost of future costs and benefits. The NPV provides a means for determining whether alternatives have net benefits, and for ranking alternatives. (Zerbe & Dively, 1994).

CBA differs from a traditional commercial project evaluation in two ways. First, it considers costs and benefits to all members of society and not only the monetary expenditures and revenues of the company responsible for the action. Second, it adopts a social discount rate that could be different from the private discount rate, because it takes into account the social opportunity cost of resources rather than the strict financial opportunity cost (Moore et al, 2004; Moore et al, 2013).

The US Army Corps of Engineers has been using CBA to evaluate public projects since the 1930s, but CBA did not become mandatory for Federal agencies until the 1980s. President Clinton (Executive

Order, 1993) and President Obama have restated the relevance of CBA, and have extended the scope of the evaluation to include distributive effects and equity concerns (Executive Order, 2011).[1]

The UK requires CBA in the appraisal of transportation infrastructure projects. In contrast, the European Commission supports cost effectiveness analysis for evaluations of programs or projects, to assess the choices in the allocation of resources, to determine strategy-planning priorities and to conduct complex evaluations. CEA can be undertaken in the context of ex ante, intermediary or ex post evaluations (European Commission, 2005).

Critics of CBA argue that it has several disadvantages. First, benefits are often difficult to quantify and cannot be reduced to monetary values (Harrington et al., 2009) Second, it is difficult to account for uncertainty (Sinden et al). Third, its complexity creates the potential for manipulation based on pre-existing biases. (Sinden et al., 2009). Fourth, the process of discounting future benefits may be inappropriate for resources (say of an endangered species) that may have increased future value. Finally, there is the concern that current CBA practices do not take into account that benefits and costs have different marginal benefits for different social groups, and, as a consequence, the results of CBA do not effectively represent the real effects of regulatory actions on collective welfare (Sinden et al. 2009).

Supporters of the CBA approach, on the other hand, argue that many of these criticisms can be addressed. Proponents also contend that as a decision procedure, CBA forces agencies to think about the outcomes of the proposed projects and regulations and quantify the economic and environmental impacts with a comparable metric (Zerbe, 1998). It pushes agencies to realistically consider the relevance and magnitude of these outcomes. The process, they maintain, at least guarantees a degree of transparency and provides a consistent framework for data collection. Monetization, though imperfect, makes possible the aggregation of dissimilar effects and allows for comparison among different alternatives provided that the same monetization factors and assumptions are held constant across projects (Sunstein, 2001; Adler & Posner, 2006). If the method of performing a CBA is transparent, the monetization of different factors can be re-evaluated if new information arises.

2.1.2 Difficulties in Applying CBA

The practice of CBA produces numerous challenges. Selection of the interest rate at which future costs and benefits are discounted is one of the most controversial. Discounting takes into account the different value that society attributes to future gains and losses as compared to the value of present gains and losses. It is based on the principle that individuals and society value present benefits more than otherwise equivalent future benefits. The discount rate affects the NPV of each alternative and is therefore a central element for assessing each alternative’s social value, and for identifying the alternative that maximizes societal welfare.

The choice of a discount rate can favour some projects over others. Low discount rates value long term benefits and costs, while high discount rates place greater value on shorter term benefits and costs. Typically, lower discount rates are chosen if the project produces benefits far in the future. For example, rail improvement projects can often have useful lives stretching out 50 years, whereas other infrastructure projects might only have useful lives of 20 years. However, if individuals and society value present benefits more than future benefits, then a single discount rate does not accurately

[1] Projects financed from EU funds need to be supported with a cost-benefit analysis method.

reflect valuation over the project lifetime (Weitzman, 2001). For this reason, the discount rate is actually an average of different rates for different future time intervals, leading to a future average rate that is lower for long lasting projects than it is for projects with a shorter useful life. The discount rate is an especially important issue when considering projects that may generate benefits far into the future, as in the case of GHG reduction policies. Conventional discounting reduces very long term benefits to near zero, while the implementation costs of such policies are born in the short term (Dasgupta, 2008; Gollier, 2012).

A fundamental critique to using a discount rate is based on the notion of intergenerational justice (Rose-Ackerman, 2011). Although the primary driver of the discount rate is the time value of money, some analysts are concerned that a high discount rate may encourage actions that disadvantage future generations. One way of dealing with such concerns is to use alternative interest rates. For example, the White House Office of Management and Budget requires US agencies to use two different rates (3 percent and 7 percent) that serve as an upper and lower bound of future benefits, and to apply the same rates to both benefits and costs. In other countries, analysts test the sensitivity of the results to changes in the interest rate.

To avoid the issues with quantifying social benefits, US agencies often estimate the cost effectiveness of their regulatory decisions. They estimate the costs of the project but do not monetize benefits. For example, they may compare quantities of emissions reductions among alternatives and choose the one that minimizes the unit cost of pollution reduction. This approach does not work well for regulations and projects that affect different factors with diverging cost effectiveness ratios.

2.1.3 Some recent applications of CBA in maritime transportation

The cost benefit approach has been used to assess the feasibility of many transportation infrastructure projects (Priemus, Flyvbjerg, and van Wee, 2008), but there are few examples of CBA for the types of projects that were part of this study.

One of the few examples of an extensive cost benefit analysis of emissions mitigation strategies of maritime transport is the EPA's regulatory impact assessment (RIA) of its 2009 strategy to reduce airborne emissions of U.S. flagged large ocean going vessels with category 3 diesel engines(EPA, 2009).

The analysis assumed that costs borne by the private sector to comply with the new regulations will be passed on to the consumers and, thus, treated them as social costs. The assessment quantified both investment and maintenance costs. Capital investment costs were estimated only for upgrading the US flagged vessels. Operational costs to maintain the equipment to reduce NO_x emissions were estimated for both domestic and international vessels. The differential price of lower sulfur fuel compared to the price of high sulfur fuel was also included for both domestic and international vessels. Future high and low sulfur prices were projected with the World Oil Refining Logistics and Demand (WORLD) model.

To quantify and monetize the benefits of the strategy, the assessment focused on the benefits to human health of improved air quality and reduced concentrations of $PM_{2.5}$ and ozone. The study explicitly excluded other smaller benefits, like the reduction of sulfur and nitrogen depositions and improved visibility using $PM_{2.5}$ and NO_X as proxies for total pollution.

Quantifying and attributing a monetary value to the health effects of the strategy is a complex process that relies heavily on existing modeling tools and on specialized knowledge of the marine transportation industry and of the health effects of criteria pollutants.[2] This analysis concluded with a comparison of costs and benefits and claims that: "the annual benefits of the total program will range between $47 to $110 billion annually in 2020 using a three percent discount rate, or between $42 to $100 billion assuming a 7 percent discount rate, compared to estimated social costs of approximately $1.9 billion in that same year." (EPA, 2009; p. 6-32).

Other studies of port related emissions reductions strategies have a much smaller scope than EPA's RIA. In order to compare different SO_2 mitigation strategies in the maritime sector, Wang and Corbett (2007) evaluated costs and benefits of reducing SO_2 emissions from ships operating along the US West Coast. The authors tested two different sulfur control strategies: a wide versus a narrow emissions control area along the coast of the Northwest United States. Additionally, they studied the costs and benefits of adopting two different types of low sulfur fuels (1.5% and .5% sulfur content), eestimating the quantity of fuel used in each area and the amount of SO_2 emissions reaching land from each control area in the baseline conditions. They defined the costs of their strategies as the differential between more costly low sulfur fuels and a cheaper high sulfur fuel and calculated the benefits as a function of the savings in SO_2 emissions and of the avoided health and environmental damages of SO_2. Based on previous studies that estimate the monetary value of avoided SO_2 emissions, they calculated the benefit/cost ratio of the four alternatives and concluded that all the alternatives have a ratio larger than 1.

Tzannatos (2010) estimated the cost/benefit ratio of reducing SO_2 emissions from marine shipping in Greece. The study estimated SO_2 yearly emissions and differential costs in the Greek seas for domestic passenger and freight shipping and for international shipping using fuels of different sulfur content. Social costs using previous research on the quantification of sulfur effects on mortality and morbidity and on building materials was also estimated. The analysis finds that the external benefits of the application of 1.5% and 1% sulfur limit to marine fuels will outweigh the increase in fuel costs. It also finds that the benefits associated with very low sulfur fuels (0.1%) do not outweigh their costs, but that SO_2 scrubbers on domestic shipping vessels provide emission reductions similar to those attained with 0.1% sulfur fuels and their benefits outweigh the yearly cost of installation and maintenance.

A limited number of studies have included the evaluation of the cost/benefit ratio of emission reduction devices taking into account a larger range of air emissions. Jiang and al. (2012) estimated the costs and benefits of sea water scrubbers (SWS). The authors first estimated a "baseline" cost of emissions for a typical return trip of a 5,000 Twenty-Foot-Equivalent-Unit (TEU) container ship between Gothenburg and Rotterdam. They used marginal external costs for emissions of SO_x, NO_x, $PM_{2.5}$ and CO_2 estimated by an EU-wide study and applied emission factors derived by previous studies for three different ship conditions: free sailing, maneuvering and berth time. They estimated the yearly costs of installing and maintaining SWS. They provided an estimate of their monetary benefits and claim that the additional cost of installing SWS on new ships can be offset by one round trip per year, and the additional costs of retrofitting existing vessels can be offset by two round trips per year.

More recently, Jiang et al. (2014) compared the benefit/cost ratio of scrubbers and low sulfur fuels based on the typical return trip of a typical medium size container ship between Gothenburg and

[2] EPA has set National Ambient Air Quality Standards for six primary air pollutants called "crieteria pollutants": NO_2, Pb, SO_2, CO, PM_{10} and $PM_{2.5}$

Rotterdam, and concluded that low sulfur fuels' benefit/cost ratio is far more favorable than the benefit/cost ratio of installing scrubbers, contingent on the price of low sulfur fuel.

Other studies examined the cost effectiveness of alternative ways to reduce emissions from operations. Using similar procedures, the Port of Long Beach (Environ, 2004) and the Port of San Diego (Yorke Engineering, 2007), estimated the cost effectiveness of providing shoreside electrical power for ships to plug in (cold ironing or alternative maritime power-AMPing). The Port of Long Beach selected 12 vessels and berths, and compared the cost effectiveness of providing cold ironing facilities to each type of vessel, taking into account the effective number of yearly port calls and the actual docking behavior of each vessel. The study estimated the capital and maintenance costs of improving the electrical infrastructure at each berth and of retrofitting the vessels to receive shoreside power. Criteria pollutant reduction by connecting the ships to the electrical grid rather than using their auxiliary motors to produce electricity while docking was calculated. From the perspective of the steamship lines, the results showed that cold ironing is cost effective as an emissions reduction strategy for steamship lines whose vessels make frequent port calls and spend longer time at berth. However, the net economic benefit to the steamship line is highly variable and dependent upon the cost of bunker fuel. In addition, the study compared alternative emission reductions strategies such as combustion management, engine replacement, fuel replacement and exhaust treatment and concluded that fuel replacement would be more cost effective than any other emission reduction technique.

The EPA's Office of Transportation and Air Quality (OTAQ) evaluated the cost effectiveness of retrofitting nonroad equipment such as cranes and other heavy equipment with four different devices to reduce NO_x and Particulate Matter (PM) emissions. Using NONROAD, a proprietary model that EPA has developed to estimate nonroad mobile equipment, and information on operation times, the study estimated baseline emissions of NO_x and PM for each type of nonroad diesel equipment. It assessed the abatement potential of the four different strategies using data from a Retrofit Technology Verification Program run by the agency. It then estimated capital costs for the different strategies. The projected emission reductions over the lifetime of the equipment and cost effectiveness of the four strategies was quantified. Results showed that upgrade kits for NO_x reductions and selective catalytic reduction systems are more cost effective than diesel oxidation catalysts and catalyzed diesel particulate filters for every nonroad diesel equipment category (EPA 2007).

It is appropriate to ask why CBA is so seldom used in the maritime sector. Possible explanations include:

- The maritime sector is mainly private, and the calculus for private decisions is based upon costs and benefits to the firm. Thus there is little justification for using a decision tool that is costly, complicated, and oriented to cases where government funding or societal costs and benefits are involved.
- Until relatively recently, the maritime sector has not been a target of government regulation. Thus policies that might trigger a CBA were uncommon. The studies reviewed are illustrative: all deal with emissions reductions strategies from the last decade.

2.1.4 CBA and port innovations

The following section reviews general considerations about the societal impacts of port innovation and their consideration in the decision as to whether a CBA should be performed.

Innovations may be implemented as a test or proof of concept of a particular strategy to address a problem, as in the examples of emissions reductions strategies described in the previous section.

However, the anticipated benefits of such a project are in its scalability for wider implementation. The test case may be more costly (new projects have high initial costs) and hence a CBA may show lower or negative net benefits relative to what larger scale implementation would show. In addition, innovation is by definition uncertain, and in a CBA context, the cost/benefit stream would have to be adjusted for this risk.

A CBA may have a different definition of the “universe” for which benefits are assessed. In theory, a CBA should include all benefits and costs no matter where they occur. However in practice this does not always occur. A CBA may include only benefits that accrue to one or more countries, or to a specific locality. Typically, the universe of benefits will correspond to the interests of the sponsoring agency. For example, if funds come from the EU, the benefits must occur within the EU to offset the costs. Practice in the US is similar. As the vast majority of projects in the United States for which CBA is performed have received federal funding, it is common for benefits or costs that accrue outside the United States to remain unquantified. When boundaries are placed on what costs and benefits are counted, the true net benefits may be quite different. For example, a US-based CBA may count revenue associated with cargo shipments diverted from Canada to the US as a benefit, when in fact such a diversion is actually a transfer, with no net benefit to society as a whole.

Emissions benefits are a key component of CBA for the transport sector in both the United States and Europe, however the specific quantification of benefits is distinct. In the United States, NOx and carbon monoxide, the key precursors of ground level ozone, are the principle targets for emission reductions. More recently, the value of PM_{10} emission reductions have grown as the connection between particulates and cancer rates has been more conclusively demonstrated (Hamra et al. 2014). CO_2 benefits are more frequently the central focus of European CBA with $C0_2$ sometimes used as a proxy for all emissions.

The rate at which future projects are discounted is often key to whether the benefit cost ratio is above one, and hence whether the project merits further consideration. For government projects, the choice of discount rate depends on assumptions regarding the appropriate social cost of capital. Another factor that influences net benefits is the durability of the innovation or project. If the project is the installation of cranes that allow for twin 40’ lift capacity with a useful life of twenty years, all of the costs and benefits are amortized over the twenty years. This shortens the stream of benefits, making it more difficult to yield net benefits than in the case of a project with a longer useful lifetime – say 50 years – all else equal.

Cost effectiveness analysis is more typically used in cases where one or more outputs cannot be monetized in a manner that is agreed upon by all involved parties. The most common occurrence of cost effectiveness analysis is in studying medical outcomes. For example, if intervention A costing 10 million Euro will reduce strokes in humans by 1000 incidents per year, a definitive statement can be made about the cost per abated stroke. However there may be no agreed upon measure to monetize the benefit, i.e. how valuable to society is the value of one avoided stroke, on average? In these cases, the benefits simply remain non-monetized. Cost effectiveness analysis was originally developed by the military to compare effectiveness of similar interventions where the specific benefit, e.g. added security, is very difficult to monetize.

In most cases, the innovations associated with ports are more readily quantifiable. Furthermore, the outputs of innovations typically have agreed upon per unit values such as an innovation reducing CO_2 by a specific number of metric tons. Yet there may be innovations that create impacts for which no per unit value has been reliably established, such as new dredging techniques that result in lower rates of turbidity in the surrounding water.

As maritime innovations are by their nature experimental, the level of benefit is usually the biggest uncertainty. For example, we might not know if a particular innovation will produce a 30% labor savings or only a 10% labor savings, or whether another innovation will produce a substantial emissions reduction or only a modest emission reduction. Conventional forms of both CBA and CEA have limited capacity to consider uncertainty (Graham, 1981; Bock and Truck, 2011). One obvious approach is to use a range of estimates for key parameters. More importantly, the learning provided by testing an innovation may be its greatest benefit, something that would be very difficult to monetize. CEA also has weaknesses for projects with uncertain outcomes, because there is no straightforward way to estimate the cost per unit outcome of an uncertain process.

3 Cost effectiveness analysis

The EC (2005) states that the main purpose of cost-effectiveness analysis (hereafter CEA) is to identify the economically most efficient way to fulfill an objective. In contrast to CBA, CEA considers two elements: the cost of achieving one objective and the level of achievement of that objective. In other words, a cost-effectiveness analysis generates a ratio between the inputs in monetary terms and the outcomes in non-monetary quantitative terms (Išoraite, 2005). The National Institute for Health and Clinical Excellence (2013) defines cost-effectiveness analysis as an economic study in which consequences of different interventions are measured using a single outcome, usually in natural units (for example, life-years gained, deaths avoided). Alternative interventions are then compared in terms of cost per unit of effectiveness.

The cost-effectiveness method is appropriate for the evaluation of actions in which expected outcomes are clearly identified and whose direct or indirect costs are easily measurable. If the outcome of a project cannot be clearly defined, or if homogeneous and quantifiable units cannot be determined, the use of cost-effectiveness analysis should be avoided (EC, 2005). For example, when an investment aims at reducing the amount of air pollutants which are released in the atmosphere, the effectiveness criteria for that investment could be the decrease in the daily average of the air pollutants emitted. In the rail transport sector. Mulvey (1979) creates a ranking of Amtrak routes which should be modernized by using a cost-effectiveness analysis. The same author compares the cost of upgrading the Amtrak service and the expected number of passengers. Rufolo (1986) creates a cost-effectiveness analysis taking into account the cost of introduction of articulated buses in comparison with the time gained for boarding of the passengers. Wang (2004) calculates the cost effectiveness of mobile source emission control measures by dividing the total costs by the total emissions which are being reduced. Barkan (2004) determines the cost effectiveness of a new refueling system by comparing the installation cost of the new equipment with the yearly volume of fuel saved from spilling.

4 The Decision-Making Process Used in the Innovation Cases

A traditional CBA was not used by the companies or organizations that implemented the 74 innovation cases. The traditional factors that promote the use of CBA were not present in most cases. These factors include public investments, projects mandated to reduce externalities via regulation, or major projects that include consideration of multiple alternatives. A review of the literature supports the finding that port-related decisions for innovation cases are rarely based on formal cost-benefit analysis. CBA is a complicated and costly process that requires experts to do correctly.

A CBA becomes more complex if an agency seeks to consider uncertainty explicitly, e.g. the consideration of multiple contingent outcomes as opposed to using a risk adjusted interest rate as a proxy for uncertainty. Thus, the type of CBA required to evaluate innovation projects is the most sophisticated type of CBA. Finally, since most of these innovations were made by private companies, the meaningful decision metric was about costs versus expected return on investment; and therefore did not call for the consideration of external costs.

Most cases had no associated cost-effectiveness data: limited cost-effectiveness data was available for 8 of the 74 cases. Three of these 8 cases had public subsidies which may have influenced the type of data collected and also prompted public disclosure of the data. In these cases, the government innovation champion wanted to showcase the innovation as a model for others to follow. For example, the cost of constructing and operating a seawater emissions scrubber on an APL containership was tested to compare the cost effectiveness of complying with an IMO emission control area by using higher cost compliant fuels or lower cost non-compliant fuels with scrubber treatment.

In the cases where limited quantitative assessment of the innovation was undertaken, the data was collected concurrent with or after implementation of the innovation. Thus, collecting cost-effectiveness data was one objective of carrying out the innovation. Thus, this data could potentially be used as an input to perform a CBA for future implementation of the innovation. Another potential obstacle is that companies may not be forthcoming with their cost-effectiveness data for proprietary reasons.

With little quantitative data on cost-effectiveness, the 74 cases were reexamined to develop a framework for the decision-making. What prompted these 74 organizations to undertake these innovations? If these innovations were purely an internal decision of the firm, we would not expect CBA or CEA to be used. If the innovation was a response to some form of public intervention, CBA or CEA would be more likely. Each innovation was categorized as either: 1) an internal decision made by the company for its own profit or efficiency motives; 2) an internal decision but influenced by external forces that created incentives or disincentives for the company; or 3) a response to a significant level of public subsidy. The data indicates that 37 (50%) of the projects were undertaken because of external influences, 21 (28.3%) were purely internal company decisions and 16 (21.6%) were influenced by public subsidy. The public subsidies were also actions undertaken by governments to be responsive to community or environmental concerns. Therefore, of the 74 cases, 53 (71.6%) (category 2 and 3) were influenced by external forces. This suggests that the port industry might consider being more proactive in examining innovations rather than, as in some cases examined, waiting until community and environmental pressures make innovation a necessity. There may be benefits that companies could realize by use of cost-benefit or cost-effectiveness analysis either to be more proactive in implementing innovation, to present a compelling case for government grants or subsidies, or in the case that the benefit/cost ratio would not be positive, to demonstrate to stakeholders why a particular innovation is not being implemented. Table 1 provides a summary of the decision-making factors that were considerations in the 74 innovation projects.

Table 1: Decision-making Factors[3]

Category	Examples	Objective	Decision process	Number of cases
1 Internal decision, no	Terminal	Increase	Firm	21 or 28.3 %

[3] See the appendix for individual project categories.

external incentives or disincentives	appointment system Automated stacking cranes	productivity, throughput, efficiency		
2 Strategic internal decision, external incentives or disincentives, no public subsidies or regulation	Use AF dock equipment as part of green port program Restore natural habitat as part of green port program	Increase public support, pre-empt regulation, protect business interests	Firm, sometimes with stakeholder input	36 or 50 %
3 Responsive decision to public subsidies or regulation (responses to subsidies different from responses to regs)	Subsidies for short-haul barge Scrubbers on ships	Reduce externalities, comply with regulatory requirements	Firm, government, other stakeholders	16 or 21.6 %

5 Are There Cases Where CBA or CEA Could Have Been Used?

As illustrated through the previous sections, CBA is not a tool for all applications. Some projects do not have sufficient data inputs, whereas for others the potential outputs are too speculative. In addition, the amount of data depends on capability and/or willingness of an agency to collect. Given that formal cost benefit analysis was not performed for the projects that were assessed as part of this study, we instead limit our discussion to the general types of projects that were included in the analysis that are most conducive to cost benefit analysis in order to illustrate the considerations that would go into future cost-benefit applications.

The projects in the study are divided into twelve major types. While exceptions exist, we have identified the four types of innovation that are best suited for the implementation of CBA. Projects in the other categories will tend to be assessed via internal business decisions that do not necessitate nor facilitate the use of CBA. The categories for which CBA is viable and their reasons for inclusion are described below.

Project Type 1: Innovation in Dredging - For dredging case studies, the use of CBA may be appropriate, because dredging is an activity that has substantial impact on the natural environment. Therefore, an assessment of externalities associated with the innovation would help to determine whether the economic benefits of dredging offset the environmental impacts. CBA is not typically performed in connection with dredging innovations in Europe, because it is often a private activity. In contrast, dredging in the US is performed by the US Army Corps of Engineers, and CBA has been required for all proposed dredging projects. The US experience suggests that the use of CBA does not mean that only projects that pass a benefit/cost test are implemented. The Army Corps has been criticized for advocating large projects with questionable net benefits (GAO, 2006)

Those dredging operations that are best candidates for benefit cost analysis are those that have an external benefit, for example dredging that has a comparatively lower impact on the benthic environment could be assessed to have a positive overall BCA even if it resulted in higher per unit cost. The same calculus is used for dredge spoil disposal innovations. When considering the specific dredging innovations included in the study, the “Wild Dragon” dredging technology would be a logical candidate for CBA because its benefits in terms of air emissions and economic gains would need to be assessed against additional capital cost.

Project Type 4: Technological innovation supporting the transfer of containers from one mode to another – CBA is often proposed for technological advances that improve the ability of containers to be transferred from one mode to another. There are a number of policy impacts from improvements to intermodal transferability that might produce positive externalities. For example, greater ability to transfer between modes may improve market access and thereby decrease monopolization of certain markets by certain modes. In addition, these innovations can allow the supply chain to make increased use of carbon-efficient modes like rail and barge in lieu of trucking. Environmental benefits that derive from the improved efficiency can also be readily monetized given standard monetization factors for criteria pollutants and CO_2.

These types of technological innovations are also a good candidate for CBA due to their high upfront capital cost that are often shared by public and private participants. In addition, the investment in increased intermodal capability may impact efficiency in other parts of the supply chain. For example, the implementation of an on-dock rail system to facilitate truck to rail modal shift may have undeniable benefits for supply chain efficiency, yet the consumption of terminal land as well as high capital construction costs must also be weighed.

Project Type 5: Technological Innovation to Reduce Vehicle Operating Costs – The United States and Europe have instituted policies intended to reduce vehicle fuel consumption that also tend to reduce vehicle operating costs. Yet, the impacts of these policies can ripple through society in sometimes unforeseen ways. CBA has the potential to help policymakers choose from multiple alternative strategies.

Truck vehicle operating costs are highly variable and are based on payload weight, cost of fuel, aerodynamic drag, rolling resistance, operating speed and many other factors. When fuel costs rose dramatically in the early 2000s, trucking companies experimented with a number of techniques to reduce their fuel consumption, many of which were monitored and assessed by the US Environmental Protection Agency. Some of these strategies were innocuous and may have even had other positive externalities (for example the installation of speed governors to prevent trucks from exceeding the speed limit). Other innovations, such as the replacement of paired tires on heavy trucks with single wide tires raised concern that the internal high cost of fuel to the trucking company was being exchanged for increased external costs in terms of pavement damage and accelerated rutting. The difficulty in performing CBA for these innovations was the variable nature of future fuel costs versus the known upfront capital costs of vehicle modification. Also, the long term external costs are difficult to estimate. Outside of trucking, examples of fuel cost reduction strategies came through the pilot implementation of hybrid locomotives and tug boats. Regardless of mode, modifications that reduced fuel consumption could also be assessed according to their impacts on emissions. Generally, the trade-offs of capital investment against marginal gains in operating cost are easiest to measure in trucks that perform long haul service, as slight improvements in fuel consumption, aerodynamic drag and rolling resistance are easier to measure at highway speeds than for trucks that perform local delivery service.

The other major component of vehicle operating costs that can be reduced is labor costs. The principle technique that has been proposed for reducing truck labor costs is the introduction of long-combination vehicles (LCVs) that allow one driver to carry two or three times the cargo without a net increase in axle weight. Most areas of the US and Europe prohibit LCVs due to concerns about their safety, impact on the highway system, and potential for diverting cargo from rail.

With respect to the specific case studies described in the report, the CNG truck deployment study is an example in which a CBA could theoretically have been performed. The project had an internal economic justification given that the cost of natural gas was lower than the equivalent price of diesel fuel. The projects external benefits are tied to superior CO_2 performance.

Project Type 6: Technological innovations supporting inland waterways – Inland waterway transportation is often the most carbon friendly mode of transportation. It is also the mode whose market share is often most precarious due to sharp competition with freight rail, particularly in the United States. For this reason, governments are often willing to subsidize innovations that improve the ability of inland waterways to compete and gain market share, even if the benefits of the innovation do not exceed the costs in the short term. While the inland waterway system is well developed for bulk and containerized goods in Europe, the U.S. system is still limited to the handling of bulk cargo in most markets. Therefore, U.S. agencies have shown a willingness in the past to subsidize services that handle non-traditional cargoes such as containers in order to help establish the market and also to offset prior subsidies that were received by other modes. Subsidies are also required because the slow speed for inland waterway transportation imposes additional inventory costs on shippers, which may mean that the price needed to induce modal shift must be below that of other modes. In addition to benefits from emissions and reduced congestion, modal shift to inland waterways can also produce safety benefits when carrying hazardous chemicals that would otherwise move over land. As is the case with many low probability, high impact events these benefits from averted accidents are often difficult to quantify. CBA would help to determine the level of subsidy justified, given environmental and safety benefits.

Conclusions

Cost-benefit analysis is a powerful but complex tool for informing public policy decisions. Although the cases reviewed in the BNP project were often motivated by external concerns, few were initiated by the public sector, involved public funds, or otherwise would justify a comprehensive CBA. Thus, it is not surprising that we observed no cases of CBA.

Many innovations could be described as experiments or proofs of concept. They are intended to demonstrate that a new practice or strategy can be implemented. We note that some examples of the use of cost-effectiveness analysis were for innovations that tested technology, with the purpose of determining whether the technology was worth pursuing for broader implementation. CBA and CEA often have difficulty in accounting for uncertainty, which makes the process particularly challenging for innovation projects.

CBA is not a simple process, and the decision to undergo a CBA should not be taken lightly. Of the twelve project types reviewed for this study, four types were determined to be conducive to CBA. Even within these project types, the decision to undergo a CBA is reliant on establishing a connection to external costs and benefits.

The collected innovation cases overall had very limited quantitative data on costs or outcomes. It would appear that port innovation would benefit from more formal methods of assessment and evaluation. This would enable instances where CBA or CEA could be applied to be more readily identified and the results of the analyses to be more broadly compared.

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Appendix

Type of operator	Innovation	1 Internal decision, **no external incentives or disincentives**	2 **Strategic** internal decision, external incentives or disincentives, **no public subsidies or regulation**	3 Responsive decision to public subsidies or regulation (**responses to subsidies different from responses to regs**)
	objective:	Increase productivity, throughput, efficiency	Increase public support, pre-empt regulation, protect business interests	Reduce externalities, comply with regulatory requirements
	decision process:	Firm	Firm, sometimes with stakeholder input	Firm, government, other stakeholders
Innovation in dredging				
Ship yard	DODO (dynamic operation in dredging and offshore)		x- support from Dutch Ministry not enough to influence decision.	
Ship yard	Dredge pumps (series of different pumps, flexible combination of certain components)	x		
Ship yard	Flexible spud wagon (cutdredger extended to work at sea)	x		
Ship yard	Wild dragon (new system to suit a certain type of soil)		x	
Electronic data interchange innovation				
Terminal operator	Port community system Portnet		x	
Port authority/port administration	SEAGHA - port community system		x	
Port authority/port administration	APCS			x
Shipping agent 1	Port Single Window		x	
Shipping agent 2	Port Single Window		x	
Terminal Operator	Port Single Window		x	
Lisbon port Administration	Port Single Window			x
Sines port Administration	Port Single Window			x
Customs	Port Single Window		x	
Leixoes port Administration	Port Single Window			x
Software Developer Consultant	Port Single Window		x	
Terminal operator	Administration	x		
Terminal operator	E-freight system "E-port"			x
Breakbulk terminal	APCS case: central port community system for breakbulk (initiative from the port)			x
Breakbulk terminal	Beroepsvereniging (KVBG)(goes hand in hand with AE1)		x	
Forwarder	IT data management) exchange data in smooth and efficient way		x	
Shipping company	e-transit (previous to the extended gate)		x	
Shipping company	Extended-GATE 1.0		x	
Shipping company	Extended-GATE 2.0		x	
Shipping company	Extended-GATE 3.0		x	
Inland terminal	Paperless Customs flow: import - extended gate up to the end consumer		x	
Inland terminal	Paperless Customs flow: import - paperless NCTS pilot (Port of Antwerp)		x	
Inland terminal	Paperless Customs flow: Export - paperless until deepsea terminal		x	
Inland terminal	Expansion OCR capabilities	x		
Inland terminal	Pre-notification deepsea terminals ANTWERPEN		x	
Inland terminal	Pre-notification deepsea terminals ROTTERDAM		x	
Inland terminal	Digital CMR		x	
IT innovation supporting the cargo flow				
Port Operator (Concessionaire)	3PL - Primary Gate of Leixões Port		x	
Terminal operator	3PL - Primary Gate of Leixões Port		x	
Terminal operator	Vado "Port gate"	x		
Terminal operator	Container terminal: landside	x		
Inland terminal	Corridor management system		x	
Inland terminal	Port Wide Lighter Schedule Port of Antwerp			x

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	decision process:	Firm	Firm, sometimes with stakeholder input	Firm, government, other stakeholders
Innovation supporting efficiency in loading/unloading				
Shipping corporation	Bulk carrier self-loading/unloading cranes	x		
Terminal operator	Automated Stacking Cranes		x	
Breakbulk terminal	2 Heavy Cranes	x		
Shipping company	S-BEND on LPG carriers	x		
Breakbulk terminal	All-weather terminal		x	
Port authority/port administration	All-weather terminal		x	
Breakbulk terminal	All-weather terminal		x	
Breakbulk terminal	All-weather terminal 1		x	
Breakbulk terminal	All-weather terminal 2		x	
Breakbulk terminal	All-weather terminal 3		x	
Breakbulk terminal	All-weather terminal 4		x	
Technological innovation supporting the transfer of containers from one mode to another				
Terminal operator	Tandemlift operations	x		
Trucking company	ECO Combi	x		
Trucking company	Van hool ECO Chassis	x		
Intermodal operator	New logistics intermodal door to door transport		x	
Inland terminal	Barge slots	x		
Technological innovation - reducing operating vehicle costs				
Terminal operator	Straddle carriers (from diesel to CNG)		x were doing project anyway- applied for subsidy after decision made	
Breakbulk terminal	Vans from diesel to CNG		x (pre-empt reg)	
Trucking company	CNG Class 8 Heavy Duty Drayage Truck			x
Technological innovations supporting inland waterways				
Existing shipping line (Inland barge)	Barge heavy lift Ro-Ro hybride	x		
New shipping line (Inland barge)	Palet shuttle barge - PSB		x	
Monitoring innovation - vehicles & cargo				
Terminal operator	Weighbridges			x (reg.)
Terminal operator	Advanced Gate Automation and FATS (Full Automated Truck System):	x		
Breakbulk terminal	Autotrakker	x		
Trucking company	Platform EuroTransCom (import export + re-use)		x	
Inland terminal	BCTN Portal with clients	x		

Type of operator	Innovation	1 Internal decision, **no external incentives or disincentives**	2 **Strategic** internal decision, external incentives or disincentives, **no public subsidies or regulation**	3 Responsive decision to public subsidies or regulation (**responses to subsidies different from responses to regs**)
	objective:	Increase productivity, throughput, efficiency	Increase public support, pre-empt regulation, protect business interests	Reduce externalities, comply with regulatory requirements
	decision process:	Firm	Firm, sometimes with stakeholder input	Firm, government, other stakeholders
Space innovation				
Terminal operator	Inland terminal			x
Inland terminal	CY Meerhout		x	
Inland terminal	Transferium		x	
	Modal shift (ROC)		x	
Shipper	Modal shift (collaboration with Beverdonk)	x		
	Offshore Single Point Mooring		x	
Trucking company	Transport hub	x		
Inland navigation innovation within urban context				
Inland transport operator	Distribution urbaine		x	
Inland transport operator	Distribution urbanie de voiture		x	
Container innovation				
Container broker agency	Foldable container		x	
Container broker agency	SEA 45		x	
Container broker agency	10\6 container			x (subs)
Inland terminal	Empty equipment	x		
Management innovation				
Shipping corporation	Emission scrubber on APL containership			x (sub)
Liner carrier	Efficiency leadership programme			x (reg)(maybe subs.)
Terminal operator	Terminal carbon footprint tracking			x (reg)(maybe subs.)
Port authority/port administration	Carbon footprint assessment of port of piraeus		x	
Breakbulk terminal	Carbon footprint assessment of Starbulk		x	