The Role of Risk Aversion and Lay Risk in the Probabilistic Externality Assessment for Oil Tanker Routes to Europe

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Summary

Oil spills are a major cause of environmental concern, in particular for Europe. However, the traditional approach to the evaluation of the expected external costs of these accidents fails to take into full account the implications of their probabilistic nature. By adapting a methodology originally developed for nuclear accidents to the case of oil spills, we extend the traditional approach to the assessment of the welfare losses borne by potentially affected individuals for being exposed to the risk of an oil spill. The proposed methodology differs from the traditional approach in three respects: it allows for risk aversion; it adopts an ex-ante rather than an ex-post perspective; it allows for subjective oil spill probabilities (held by the lay public) higher than those assessed by the experts in the field. In order to illustrate quantitatively this methodology, we apply it to the hypothetical (yet realistic) case of an oil spill in the Aegean Sea. We assess the risk premiums that potentially affected individuals would be willing to pay in order to avoid losses to economic activities such as tourism and fisheries, and non-use damages resulting from environmental impacts on the Aegean coasts. In the scenarios analysed, the risk premiums on expected losses for tourism and fisheries turn out to be substantial when measured as a percentage of expected losses; by contrast, they are quite small for the case of damages to the natural environment.

Keywords: Oil Spills, Probabilistic Externalities, Risk Aversion, Lay Risk Assessment, Mediterranean

JEL Classification: Q51, Q53, L91

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1. Introduction

The most recent large scale accidents in oil sea transport (Erika, Prestige, etc.) have highlighted the concern of oil spills to the environment, health, economy, and socio-economic activity. As externalities associated to oil spills have been very poorly analysed in previous work and as their impact can potentially be very high, there is a need to deepen the knowledge of these kind of externalities.

In order to arrive at a comprehensive evaluation of the external costs associated with importing oil into Europe, one needs to take into account the likely future oil demand-supply scenarios, the relative relevance of import routes and pipelines, the local specificities in terms of critical passages, the differences in terms of burdens and environmental and socio-economic impacts along the different routes and pipelines, and the development of oil spills prevention and remediation technologies and regulations. Last but not least, the intrinsic stochastic nature of the phenomenon should be carefully analysed. The perception of European citizens of the risks involved in carrying oil to Europe and the associated *risk aversion* are particularly important in this context. In order to incorporate all these features into a consistent evaluation framework, one needs to develop a methodology suitable to deal with *probabilistic externalities.* In this perspective, we develop a methodology for analyzing the risks related to oil tanker accidents. We can divide ideally this methodology design effort into a series of tasks.

The **first task** is to identify the possible causes of an oil spill. Ship-related oil pollution is attributed mostly to operational discharges, which have consistently overshadowed accidental discharges. Apparently the majority of these discharges happen either close to the mainland or within port areas and terminal stations, usually resulting in small spills that are dealt with by the local authorities and seldom reported. Less frequently, the cause of an oil spill from a tanker is an accidental event, which will be discussed in detail in the next section.

The **second task** is to evaluate the probabilities related to these types of accidents, or more precisely, for each of these causes of accident, the probability that an accident of such kind happens, and oil is actually spilt. The probabilities of a grounding, collision or a structural failure and foundering incident occurring and causing oil to be spilled are calculated through a Fault Tree Analysis (FTA).

The first and second tasks are dealt with in Section 3. In order to anchor our probability assessment methodology to a real world example, and to test the developments of such methodology, a sample route from Novorossiysk on the Black Sea coast in Russia to Augusta in Sicily, Italy, is used as a benchmark. The basic scenario considers a Suezmax type tanker carrying approximately 145’000[1] tonnes of oil cargo. The selected route has a number of special features which make it of singular importance and interest, not least the fact that it passes through the Bosphorus Straits, a highly congested and navigationally difficult sea passage passing through the heart of Istanbul in Turkey.

Four locations along the route were chosen due to a combination of the high likelihood of an accident happening in that particular site and the high environmental and socio-economic consequences that such an accident would entail. The parts of the route not considered, through the Black Sea and from the Aegean to Sicily, have a lower chance of a spill occurring due to a relative lack of obstacles. Furthermore, should a spill occur the consequences would be, again relative to the other sites, less severe due to the absence of a nearby coastline and the fact that the oil would be naturally dispersed more quickly in the open sea. As a consequence their expected risk values are orders of magnitude lower than those of the selected sites.

[1] Tankers of this class are the most likely to be used along this route. The Bosphorus cannot be navigated by tankers larger than 150’000 tonnes; moreover, small tankers are unlikely to be used along this route due to recent European regulations which have banned tankers cruising under the flag of countries notorious for having lax regulatory criteria for registering ships – medium-sized and large tankers are unlikely to be operated under these flags.

The **third task** has precisely to do with people's attitude towards risk and consists in devising a set of *criteria* to decide how each category of cost arising from an oil spill should be coupled with probabilities in order to monetize probabilistic externalities, and a *methodology* to include risk aversion and the perception of a risky situation by the public when relevant.
For external costs which directly or indirectly affect the public at large, considering risk aversion is necessary because, for the vast majority of people, the exposure to a risky situation is a source of discomfort. In a sense, risk aversion is a measure of the reluctance to be subject to uncertain negative effects. For some category of costs arising from an oil spill, such as the loss of cargo or cleanup costs, considering risk aversion is not necessary: these costs are directly borne by the oil companies or, partially, by coastal protection agencies, and do not have a direct impact on individuals. Therefore we assume that such costs enter the welfare function of a risk neutral collective agent.
On the other hand, damages to the local economies and to the local environment directly affect the utility function of individuals, and, for these categories of probabilistic externalities, we assume that, in general, risk aversion is relevant. Section 4 deals with the methodological implications of including these consideration into the analysis.

In order to illustrate our risk aversion evaluation methodology, in Section 5 we have applied it to three areas in the Greek Aegean Islands: the Northern Aegean Region, the Southern Aegean Region and Crete Region, focusing on three different types of impact of an oil spill: impacts on local economies (fishery and tourism) and impacts on local natural environment.

The analysis provides the following conclusions:

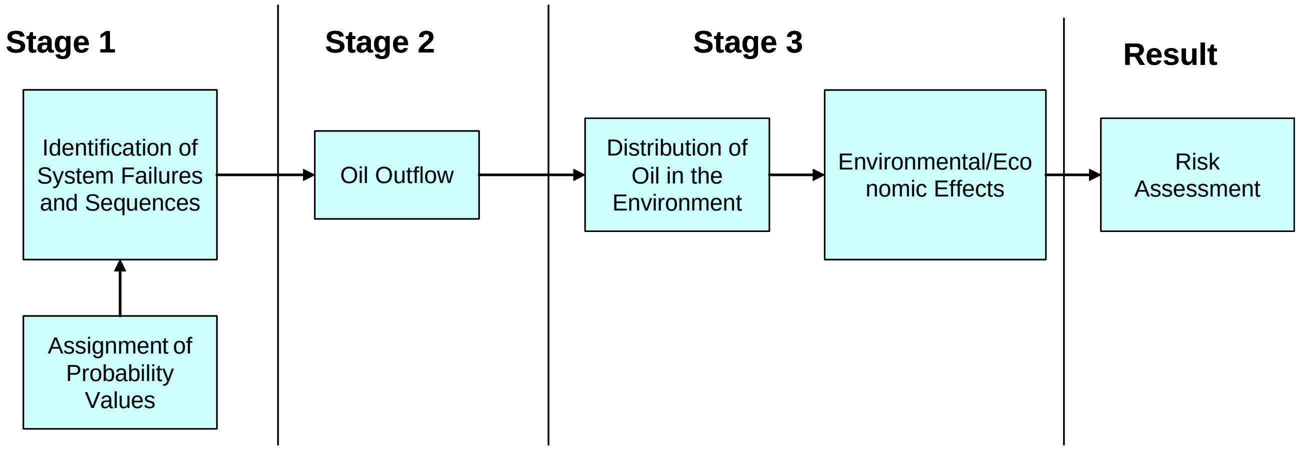
- The costs of oil spills (in terms of losses for the tourism sector, fisheries and damages to the natural environment) in the Aegean are estimated at around € 405 million in the case of a 'worst case' oil spill and around € 264 million in the case of a 'typical' spill.
- The 'expected value' of these losses – i.e. the costs referred to above times the associated probabilities is € 22'662 for a typical spill and € 1935 for a worst case oil spill.
- These values are based on the expert probabilities. If we take indicative lay estimates of the probabilities of the accidents, which could be as much as 100 times higher, the expected costs will also increase by a factor of 100.
- The risk premiums on these expected costs are not negligible when measured as a percentage of expected costs for tourism and fisheries (on average about 90%, 40% and 23% in Northern Aegean, Southern Aegean and Crete respectively, , but up to 350% for particularly affected groups); by contrast, they are quite small for the case of damages to the natural environment (around 0.8% in all regions). Assuming higher accident probabilities does not change much the overall regional ratios of risk premiums to their correspondent expected costs for a given accident; it does however increase these ratios, for the most vulnerable groups, when risk premiums are broken down for different impact groups. Also, the absolute values of risk premiums increase considerably assuming lay probabilities.
- Future work is needed to assess the lay probabilities more carefully and to examine more sites/routes to increase our understanding of accident costs of oil transportation by sea.

2. Probability assessment methodology

The intrinsically probabilistic nature of the externalities related to oil transportation, and in particular to oil spills from oil tankers, calls for an extension and adaptation of the externality assessment methodology in at least two respects.

First, one needs to determine the probabilities attached to the events liable to cause external damages. Second, one needs to assess to what extent the mere fact of being confronted with an uncertain event with likely negative consequences affects the welfare of the concerned individuals. These two tasks are crucial elements of the more comprehensive task of assessing the externalities related to oil transportation, which proceeds via the following framework pathway (Figure 2-1).

Figure 2-1. Outline of risk analysis methodology



The focus of this Section is on Stages 1 and 2 for the determination of the probabilities of the initiating events.

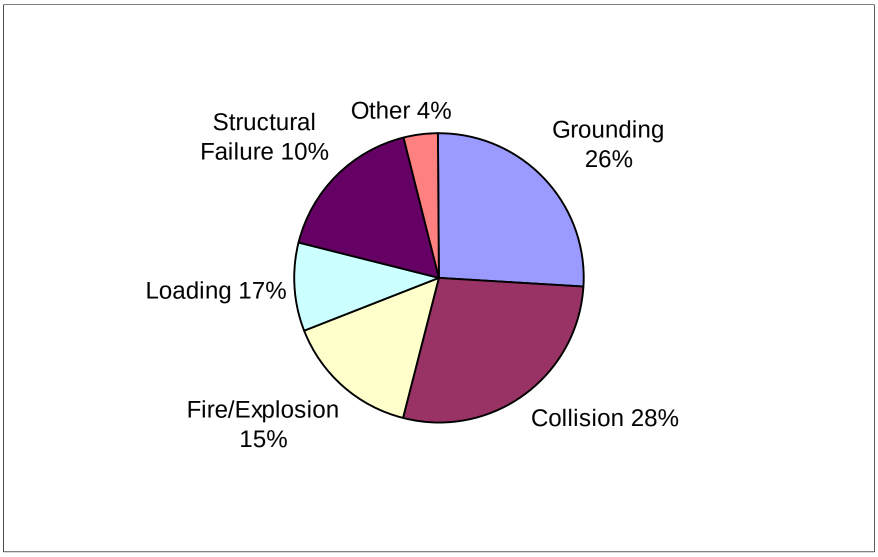
2.1. Causes of oil spills

The first task is to identify the possible causes of an oil spill. Ship-related oil pollution is attributed mostly to operational discharges which have consistently overshadowed accidental discharges. Apparently the majority of these discharges happen either close to the mainland or within port areas and terminal stations resulting usually in small spills which are dealt with by the local authorities and are seldom reported.

Less frequently, the cause of an oil spill from a tanker is an accidental event. Figure 2-2 reports the distribution of oil spill causes in recorded oil tanker accidents. The most likely causes of accidental oil spills are grounding and ship to ship collision. Fire and explosion used to be significant causes of accident. Their importance is now negligible, due to recent changes in unloading regulations that prevent the formation of explosive gas mixtures in the hull. Structural failures, foundering and loading-unloading errors can also cause sizeable spills; in these cases the human element, which can play a role also in case of grounding and collision, is particularly important. For a residual fraction of the accidents so far recorded the cause could not be identified with certainty.

The rest of this work focuses on *groundings, collisions* and *structural failure & foundering* as these are the most likely sources of accidental oil spills. In particular, in the Aegean case study we disregard accidents due to fire explosion in view of the safety improvements described above, and accidents due to loading and unloading because crude oil tankers do not engage in such activities at any port in the Aegean Islands. Therefore, assuming that oil spills in the Aegean can be originated only by one of the three surviving causes we normalise their shares as follows: *grounding: 41%, collision: 43%* and *structural failure & foundering: 16%*.

Figure 2-2. Major causes of recorded accidental oil spills[2]



2.2. Determination of probabilities of oil spills

The second sub-task is to evaluate the probabilities related to these types of accidents.
The probabilities of a grounding, a collision or a structural failure incident occurring and causing oil to be spilled are calculated via Fault Tree Analysis (FTA).
The Fault Trees used for this study were constructed to show the possible accident trajectory of opportunity which could lead to an oil spill, and standard probabilities were attributed to the initiator events. These were then combined using Boolean algebra techniques. If, for an event to occur, two or more causal events need to happen (or not happen as the case may be), then the probabilities of these two events are multiplied together. This new value gives the probability of each events occurring, commonly known in Boolean algebra as the intersection of events. This is represented by an AND gate in the Fault Tree. For example, for drift grounding to occur, four events must happen simultaneously:

1. There is a loss of steering or propulsion.
2. There is an anchor failure.
3. There is a failure in the ability of assistance to prevent the grounding.
4. There is an unsafe wind or current which propels the vessel into a place where it grounds.

Only if all of these factors occur at the same time will grounding occur.
If, on the other hand, for an event to occur only one of any number of casual events is required for an event to occur, these probabilities are added together. In Boolean algebra this is the union of events[3] and is represented by an OR gate.
For there to be a failure of assistance to prevent grounding, any one of these events is sufficient.

1. Assistance is not requested.

[2] [15]
[3] To be precise, the union is the sum of the probabilities minus the probability that the events occur simultaneously (intersect). As the probabilities used in this analysis were quite small, the intersect was negligible and therefore not considered.

2. Assistance does not arrive.
3. Assistance is unable to prevent grounding.

For the sake of simplicity, where there is a pathway that is far more important (difference is more than two orders of magnitude) than the others where only one is necessary (OR gate), only that pathway is considered. These probabilities are per tanker passage.
For *groundings and collisions*, the probabilities were calculated using data from Brown[4] using human error performance values under various situations and previous oil spill statistics.
For *structural failure and foundering*, FTA was conducted on the basis of expert probability assessment; however, the resulting probabilities were double checked against actual spill data and a found to be consistent with observed accident frequency for reasonable parameter values.

Two calculations were made for each site: (a) the probability of a spill occurring and being of an average size and (b) the probability of a "Worst Case Scenario".
A Worst Case Scenario is defined as loss of 90% of cargo (spill size =130'000 tonne) where the cargo is 100% crude oil.
The probable spill size and the likelihood that an incident comes under the Worst Case Scenario category were taken from statistics of previous tanker accidents.
Once the probabilities of each initiator event have been established, they are multiplied by a weighting factor for each site, usually based on the physical characteristics, preventive measures taken and level of spill preparedness of the location. This allows us to determine:

1. the probability that oil is spilt, given that grounding or a collision or a structural failure has occurred, and
2. the probabilities of different amounts of oil being spilt given that oil is lost.

From 1993, all new tankers above 5'000 dwt (dead-weight tons) were required to have double hulls or equivalent. 39% of all tankers had double hulls in 2001.[5] A report commissioned in the US after the Exxon Valdez disaster in Alaska showed that double-hull design reduced the number of spills (over the single-hulls) by 54 percent for the 150'000-dwt tankers. However in collisions, the double-hull vessels had a larger average spill size (given a spill) than the single-hulls, but the single-hulls had a larger maximum spill. For the grounding scenarios, in comparing average spill size given a spill, the single-hull vessel had a larger average spill than the double-hull in the 150'000-dwt size. The double-hull designs had a larger maximum spill than the single-hulls.[6]
Using the procedure sketched above, expert probabilities for an oil spill, given that an accident has occurred, have been computed for the case of Grounding, Collision and Structural Failure and foundering. The table below summarises the main findings for the Aegean Islands' case. Note that these probabilities are site-specific, as they take into account site-specific factors that influence the final probability The details of the probability assessment exercise for the route under scrutiny are not reported here for economy of space, and can be obtained from the authors upon request.

Table 2-1. Oil spill probabilities for the Aegean case study.

Accident type	Share in total accidents	Average	Worst case
Grounding	41%	1.37E-04	2.73E-06
Collision	44%	6.59E-05	6.59E-07
Structural Failure and Foundering	16%	7.40E-05	2.52E-05

4 [25]
5 [19]
6 [19]

3. Risk aversion and lay risk evaluation methodology

Once the probabilities of the events causing the externalities and the monetary value of the possible damages in the absence of any risk have been assessed, the following factors should be taken into consideration when evaluating the implications of an oil spill for the welfare of the affected individuals:

- the fact that the externalities under scrutiny are probabilistic rather than certain,
- the fact that individuals, when confronted with the perspective of being potentially affected by the consequences of an oil spill, naturally adopt an **ex-ante** perspective, rather than the **ex-post** perspective usually implicit in standard externality evaluation, and
- the fact that the public perception of the relevant probabilities is based upon information sets that typically differ from those of the experts in the field, and hence subjective probabilities held by the public are in general different themselves from probabilities assessed by the experts.

The first factor is in general referred to as ***risk aversion*** and the third factor as ***lay risk evaluation***. Both factors combine in an ***ex-ante*** damage assessment framework to add additional "virtual" external costs to those caused by an environmental accident: that is, the cost of the discomfort of being exposed to an uncertain situation with possible negative consequences, whose chances are not well understood either.

In principle, taking into account these three additional factors allows a more correct representation of the losses in welfare actually incurred by the population affected by the consequences of a spill. It is thus important to include these refinements in our externality assessment, irrespective of the size of their actual contribution to the total value of the external damages caused by the oil spill.
The methodology we propose for assessing these issues was originally developed by Markandya and Taylor [35] in the context of probabilistic externalities of nuclear accidents in France. The rest of this section will draw heavily upon the methodological sections of that report. From a theoretical economic point of view, the problems, once framed in terms of expected utility from the outcomes of a lottery, are identical, and thus their methodology can be directly applied to our task. However practical differences exists, particularly in the determination of the relevant probabilities (for which we refer to those reported in Section 2), and in the determination of the burdens and impacts to which a monetary value has to be attached. Since the order of magnitude of the variation in utility is way lower than the one usually expected from a nuclear accident, the size of the contribution of these consideration to the overall external cost of oil transportation is obviously much lower than that assessed in [35] in the case of nuclear accidents.

3.1. Methods of estimating the costs of an uncertain accident

In most analyses of accidents related to the supply of energy, damages and benefits are estimated by simply monetising expected consequences, relying on expert judgements about both the probability of consequences and their magnitude. This approach, termed Expert Expected Damage (EED), relies upon the fundamental implicit assumptions that individuals are indifferent to risk and that they share the same information about the accident under scrutiny as the experts in the field. It basically consists of multiplying the monetised expected consequences by the probability assessed

by the experts[7].The implication of this approach is that if the per capita share of the value thus computed was offered to each of the individuals affected by the accident for accepting the related risk, they would be fully compensated for the cost component of that risk actually taken into account in the assessment. Markandya and Taylor [35] note that there are some obvious and not so obvious problems with this reasoning, the most obvious one being that there may be many more effects of an accident than the analyst can track and quantify. To the extent that some of these effects are missing, the money value derived will be too low. A partial response to this problem is to take higher probabilities; in general, however, the probability used refer to design requirements and is usually very small, especially for potentially very dangerous installations such as nuclear power plants, and this in turn results in very low external costs[8].
Other partial approaches to solve the problem of incompleteness of standard practice risk evaluation are mostly ad hoc remedies which do not attempt to tackle the core of the issue in a systematic way. For instance in [38], again in the context of nuclear accidents, the suggestion is to use the square of the damages, on the grounds that an event with many deaths is valued much more highly than the same number of deaths occurring one at a time. In practical terms, under this approach one event causing 10 deaths is valued the same as 100 events with one death each. That would raise the external costs significantly but there is no empirical justification for this argument.

In the case of an oil spill, human lives are rarely in danger, but the integrity of whole ecosystems and the viability of a number of economic and social activities can be compromised for a non-negligible period. The uncertainty about what will exactly happen after a tanker has spilt several thousands of tons of oil in front of a coast, may well result in probabilities of such an accident held by the public that differ substantially from those held by the experts.
Thus the problem is analogous to the one posed by nuclear accidents, albeit at a lower level of concern.
In [35], the strategy proposed as the most likely one for resolving this issue, is to *allow more systematically for risk aversion and to use perceived probabilities in the evaluation.*

The problems addressed here may be described as a failure of the EED approach to account for individual preferences and for the context in which these preferences are expressed. In modern economics, the basis for the valuation of any commodity, including complex and non-market ones like health risks, is individual preferences as expressed in or inferred through market behaviour, or as inferred through observing other types of behaviour.
There are three issues, from an economics perspective, that arise in the expert expected damage (EED) approach:

(i) Ignoring risk aversion. The EED approach assumes that money and satisfaction, are proportionally related. The evidence in study after study, however is that people need more money to compensate them for taking risks than the actuarial value of these risks. The reason is simply that people are adverse to taking risks, particularly of the type we are considering here.

(ii) Ignoring the ex ante perspective in individual decision making. A distinction is made here between an ex ante approach and an ex post approach to making decisions when outcomes are uncertain. The ex post approach, which is part of the EED approach, assumes that individuals maximise the expected value of their welfare realised in alternative states. However, economists have found more empirical support for individuals' maximising expected utilities, which we term the ex ante approach, following [39]. The term "expected utility" is used because individuals are assumed to maximise the expected value of their utility over a state with, and a state without, the accident while accounting for the

[7] See [35] where [36] is mentioned as an application of this approach to the case of the evacuation costs for a nuclear accident.
[8] An exception is [37], where probabilities 300 times higher than the design one for nuclear power plants are used.

probability of each state occurring. This may be distinguished from the EED approach where one estimates the loss in satisfaction from the consequences of an accident if it occurred with certainty and then multiplies this amount by the probability that the accident will occur.

(iii) Ignoring lay risk assessments. The EED model as described above is based on expert assessment of the probabilities of uncertain events. Studies have shown that, at least for the nuclear case, the lay public believes these estimates are far too low. Further, the public has been shown to hold a complex, multi-attribute definition of nuclear risks, encompassing much more than probabilities and consequences--incorporating trust, controllability, dread and other concerns that are outside of the purview of an expert risk assessment. The distinction between expert and lay assessments of risk does not mean that either is incorrect. However, it suggests that, since damages are estimated based on individuals' willingness to pay (WTP) to avoid risks, it is more appropriate to estimate damages based on lay perceptions of risk since their willingness to pay is based on their perceptions. This idea is equally applicable to all of the fuel cycles, though assessments of the nuclear fuel cycle are unusually sensitive to this distinction.

In theory, unless these issues are addressed, the sum of money estimated as the damage will not match the amount needed to make whole those potentially harmed. Accordingly, an alternative paradigm is suggested here, termed expected utility (EU) approach, that incorporates risk aversion, the ex ante perspective (i.e., expected utility maximisation), and lay perceptions of risks. The EU model is then used to simulate the consequences for damage estimates of substituting the EU model for the EED model using the "state-dependent utility function approach" alluded to above.

As is the case for nuclear accidents, it easily can be argued that the public may view risks connected to oil spills holistically, not distinguishing in their assessments of risks between the various impacts. If this is true, one cannot, even conceptually, apply the EU (or EED) model to each impact of oil spills and sum the resulting damage estimates. Rather, the EU model must be defined over all impacts simultaneously to derive a holistic damage estimate.

In [35] it was necessary to assume that the public's preferences are additive and separable across stages of the nuclear cycle. We have to take a similar assumption, namely the public's preferences are additive and separable across the various impacts on an oil spill.
Such an assumption permits us to focus on each impact of oil spill in turn and then sum up the damage estimates and to compare it to estimates of damage derived from the EED approach, which necessarily views expected consequences of each impact as additive and separable.

3.2. The Expected Utility Model

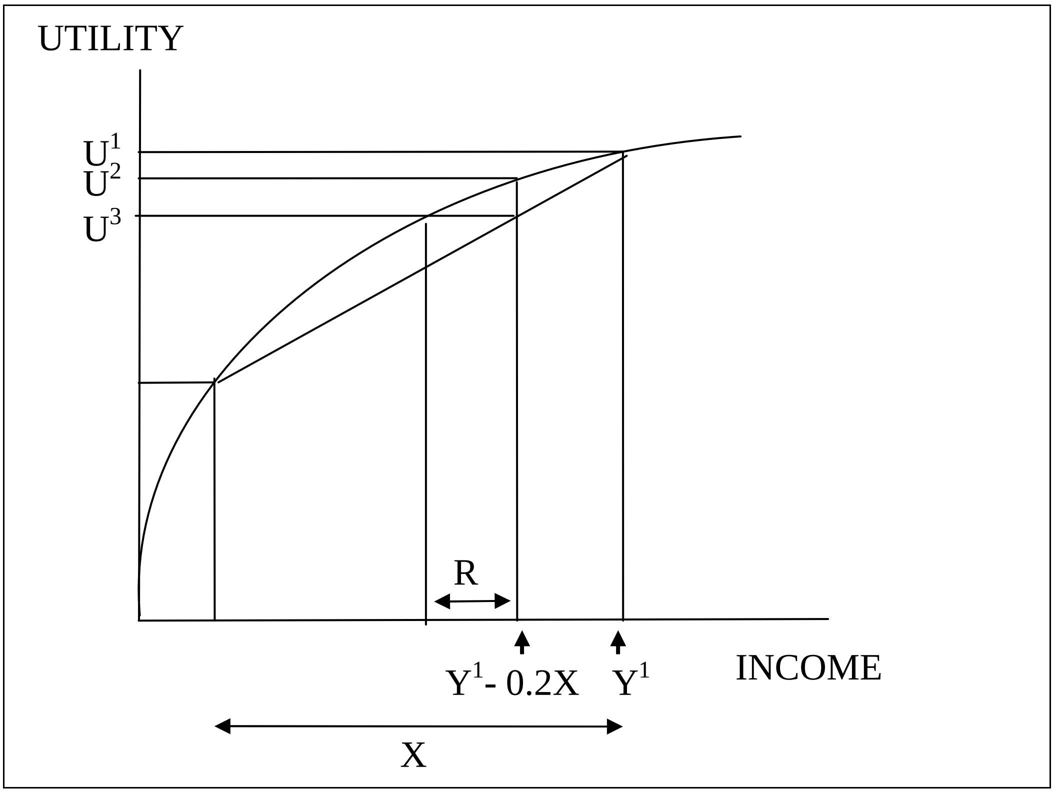
We replicate here the description of the theoretical model as proposed in [35]. As noted above the theoretical framework is identical for the two problems. The only difference in our approach is that we used a more general functional form for the power utility function, which allows a more extensive sensitivity analysis.

The expected utility model can be best explained with the use of an example. Suppose that an increase in emissions of a pollutant result in a risk of a non-fatal cancer, which cannot be treated in a preventative way but only once it has been diagnosed. Then it can be eliminated with no pain and suffering but at a cost of X € to the individual. If the risk of getting that cancer is two parts in ten, then 0.2X is the 'expected value' of the damage.[9] However, the willingness to pay to avoid the risk is

[9] The numerical values are not intended to be realistic (0.2 is a very large risk), but are chosen to make the figure easier to interpret.

greater than that as can be seen in Figure 3-1 below. Each level of the individual's income is assumed to have associated with it an utility U and the shape of the utility curve is as shown, with additional utility declining as income increases. The present level of the individual's utility is U^1 and his income is Y^1. With the increased risk of a health impact, the expected income falls to Y^1 - 0.2X, and the utility associated with that uncertain event is U^3. However, the individual is willing to pay more than 0.2X to eliminate this uncertainty, because he can obtain the same level of utility (U^3) as the expected one associated with his expected income with a level of income equal to Y^1 - 0.2X - R. 'R' is said to be the risk premium associated with the uncertain event or the amount over and above the expected costs of the event that the individual will pay.
Estimating the risk premium is very important, especially when it comes to environmental damages related to health and to accidents. It is also important to note that the premium will depend not only on the shape of the utility function (which indicates attitudes to risk aversion), but also on the perceived probabilities of the damages. There is some evidence to indicate that, for events with small probabilities of occurrence, the subjective probabilities are often much higher than the objective ones.

Figure 3-1: Risk Premium in Valuing Damages



3.3 Choice of the utility function

As noted above the degree of risk aversion depends on the concavity of the utility function. There are two main measures of this concavity: the coefficient of absolute risk aversion and the coefficient of relative risk aversion. Given a utility function of the form

$$U = U(W) \quad (8)$$

Where W is the wealth of the individual and U its utility, absolute risk aversion is given be A_r and relative risk aversion is given by R_r where

$A_r = -U''(W)/U'(W)$ (9)
$R_r = -W\, U''(W)/U'(W)$ (10)

U' is the first derivative of U with respect to W and U'' is the second derivative of U with respect to W.

The terms "absolute risk aversion" and "relative risk aversion" are tied to the nature of the lottery. Absolute risk aversion applies to additive lotteries that are expressed in monetary units while relative risk aversion applies to multiplicative lotteries in rates or fraction. In our case, the monetary consequences of accidents will be expressed in terms of percentage of loss wealth. We will thus use the relative risk aversion coefficient (R_r).

From the theoretical point of view, various functional forms of utility functions have been studied which reflect different attitudes towards risk. Many experimental studies have also been developed to estimate the risk aversion coefficient of individual decision-makers by presenting them lotteries (i.e. a set of probabilities associated with different loss of wealth) and by letting them rank these lotteries[10]. These studies usually show that the absolute risk aversion decreases with wealth. As far as relative risk aversion is concerned, they seem to support the idea of a rather constant coefficient of relative risk aversion. As a consequence, the most general way to express suitable potential functional forms of the utility function is a power function [31] defined by:

$$U(W) = \frac{1}{\gamma}\left[1 - \exp\left(-\gamma\left(\frac{W^{1-\sigma}-1}{1-\sigma}\right)\right)\right], \sigma \geq 0, \gamma \geq 0. \quad (11)$$

When $\gamma = 0$ this function boils down to

$$U(W) = \frac{W^{1-\sigma}-1}{1-\sigma} \quad (12)$$

and exhibits positive and decreasing absolute risk aversion, while the coefficient of relative risk aversion (R_r) is constant and amounts to σ. The logarithmic specification U(W) = lnW (implying that the coefficient of relative risk aversion is equal to unity) can also be derived as a special case of the power function (11) by choosing $\sigma = 1, \gamma = 0$.
If the individual is risk neutral, the relative risk aversion coefficient is zero, and the corresponding utility function is: U(W) = W.

3.4. Risk premium computation

The Willingness to Pay of a risk averse individual for avoiding a risky situation can be computed by comparing what would be the welfare change of a risk neutral individual and the correspondent of a risk averse one. We label these welfare losses respectively, **cost of accident without risk** and **cost of accident with risk.**

To fix ideas, suppose that a risk averse individual living in a coastal area faces the lottery. During a given year, with probability $p_{,1}$ the shore of its place of residence will be affected by a moderate oil spill. With probability p_2 ($p_1 > p_2$), the shore of its place of residence will be affected by a much larger oil spill. If a moderate oil spill takes place, the per capita damage for the inhabitants of the affected area is X_1. If a more substantial oil spill takes place, the per capita damage for the inhabitants of the affected area is X_2 (with $X_1 < X_2$). With probability $p_0 = 1 - p_1 - p_2$, no oil spill

[10] See [40], [41], [42], [43], [44].

will affect his place of residence and hence no damage would occur. If W_0 is the wealth of the individual under scrutiny, her situation in the three possible state of the world is summarized in the following Table:

Table 3-1. States of the world for a simple oil spill lottery

State of the world	Probability	Wealth
No Spill	$p_0 = 1 - p_1 - p_2$	W_0
Moderate Spill	P_1	$W_0 - X_1$
Very Large Spill	P_2	$W_0 - X_2$

Now, for a risk neutral individual, the **cost of accident without risk** is simply

$$CA_{RN} = W_0 - E(W) = W_0 - \left[(1 - p_1 - p_2)W_0 + p_1(W_0 - X_1) + p_2(W_0 - X_2)\right] \quad (13)$$

where $E(W)$ is the expected value of the individual's wealth.

On the other hand, for a risk averse individual, the **cost of accident with risk** is

$$CA_{RA} = W_0 - U^{-1}\left[E\left(U^*\right)\right] \quad (14)$$

where $U^{-1}\left[E\left(U^*\right)\right]$ is the so- called *"certainty equivalent"*, that is that value of wealth that yields the same level of "satisfaction" to the (risk averse) individual as being exposed to the lottery.

In terms of the power function (11), the certainty equivalent is

$$U^{-1}\left[E\left(U^*\right)\right] = \left[1 + (1-\sigma) * E\left(U^*\right)\right]^{\frac{1}{1-\sigma}} \quad (15)$$

where

$$E\left(U^*\right) = \left[(1 - p_1 - p_2)U(W)_0 + p_1 U\left[(W_0 - X_1)\right] + p_2 U\left[(W_0 - X_2)\right]\right]. \quad (16)$$

This is the step where concavity plays a crucial role. Note in fact that, for a risk neutral agent, the certainty equivalent is *E(W),* since is utility function is simply *U(W) = W.*

The risk premium is then computed by looking at the difference between the two welfare changes, or

$$RP = CA_{RA} - CA_{RN}\ . \quad (17)$$

4. Application of risk aversion and lay risk evaluation methodology: a case study on the Aegean islands

From the theoretical discussion of Section 3 it is clear that four main ingredients are needed in order to integrate both Risk Aversion and Lay Risk consideration into the assessment of a probabilistic externality:

1. a set of "objective" (or at least, realistic) probabilities of occurrence of the accident causing the externality;
2. the monetised value of the damages that could be caused by the accident; this involves individuating the sectors affected and the degree by which they are impacted by an oil spill;

3. a concave utility function for the individuals affected by the externality, parameterised in such a way to yield a realistic representation of risk aversion;
4. for the lay risk assessment, a reasonable hypothesis about the degree by which probabilities held by general public differ by those deemed realistic by experts in the field.

As to the first ingredient, we rely upon the probabilities of occurrence of an oil spill in an average and worst case scenario for the Aegean leg of the Novorossiysk - Augusta tanker route, as specified in Table 2-1;
As to the second ingredient, we focus on the case of Aegean Sea Islands, one of the “hot spots” of the Novorossiysk-Augusta tanker route.
As to the third ingredient, we consider a range of power utility functions (12), which include the logarithmic utility function as a special case, and rely on sensitivity analysis to check the impact of choosing different specifications.
As for the fourth ingredient, we will present a simple example of lay risk assessment under the somewhat arbitrary, alternative assumptions that Aegean residents hold subjective probabilities of an oil spill affecting the Aegean Islands either 20 or 100 times higher than probabilities computed in Section 2. In the nuclear field, observed lay risk probabilities were about 20 time higher than expert ones. However, since 20 was the factor observed for very specific kind of accident (nuclear accidents in France), we compare the results obtained using this factor to those that can be obtained by prudentially setting lay risk probabilities to much higher values, that is, by multiplying expert probabilities by a factor of 100.

4.1. The Aegean Sea Islands[11]

This case study considers three Regions of the Aegean Sea: Northern Aegean Region, Southern Aegean Region and Crete Region.
The Aegean Sea is located between the coasts of Greece and Turkey and the islands of Crete and Rhodes. It covers an area of 210 square kilometres and contains over two thousand islands of varying sizes, most of which belong to Greece. The Aegean is also filled with submerged rocks and island populations that depend on fishing and tourism for their livelihood. It has been named as a key area of the Mediterranean in need of protection by the World Wildlife Fund.
This area of the Mediterranean has a massive amount of tanker traffic, as it is here that tankers travelling from the Black Sea and the Suez canal converge, increasing the likelihood of a collision.

The Northern Aegean region lies northeast of the Greek mainland. The region of the Northern Aegean has a population of 206’000, representing 1.9% of the country’s population and contributing 1.7 % to the GDP (2004). About 59’000 residents are employed in public and/or private enterprises, 21% in agriculture, 22% in foods and drinks industry, non-metal products manufacture and furniture manufacture and 57% in tourism. The region’s tourism sector counts 398 firms and 5’478 workers, and represents the 3.1% of the GDP (2004). The fishery sector counts 2’239 workers and contributes 2.58% to the GDP (2004).

The Southern Aegean region, more commonly known as the Dodecanese and the Cyclades region, consists of two groups of islands in the Southern Aegean Sea. The region has a population of 302’000, representing 2.8% of the country’s population and contributing 3.1% to the GDP (2004). About 95’000 residents are employed in public and/or private enterprises, 9% in agriculture, 22% in foods and drinks industry, non-metal manufacture and clothing manufacture and 69% in tourism. The region’s tourism sector counts 1’858 firms and 17’839 workers, and represents the 18.7% of the GDP (2004). The fishery sector counts 3’586 workers and contributes 3.8% the GDP (2004).

[11] [32]

Crete is Greece's largest and southernmost island. It has a population of 601'000, representing 5.5% of the country's population and contributing 5.3% to Greece's GDP (2004). About 230'000 residents are employed in public and/or private enterprises, 31.4% in agriculture, 13.6% in foods and drinks industry, textile manufacturing and production of plastic products and 55% in tourism (2004). The region's tourism sector counts 1'337 firms and 26'792 workers, and represents the 13.1% of the GDP (2004). The fishery sector counts 1'161 workers and contributes 0.4% to the GDP (2004).

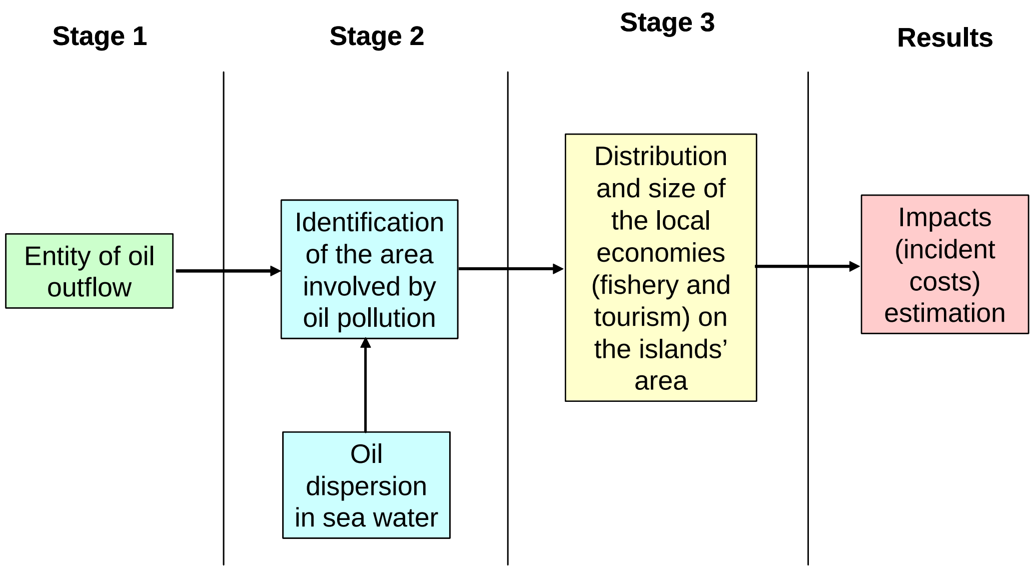
4.2. Externalities considered in the case study

The most important impacts of an oil spill in the case of islands like Aegean Island are those on *environment* and on local specific economic sectors, namely *tourism* and *fishery*. We do not consider as externalities *cleanup costs*, because we assume they are not borne by local communities and, for the sake of simplicity, we assume that individuals are risk neutral regarding these costs.

4.3. Estimation of the impacts on local economies

To estimate impacts on tourism and fishery sector, first of all, it is necessary to identify the area involved by oil pollution, which is a consequence of the amount of oil that is released and of the way it is dispersed in sea water. Then, we have to look to local economies, and in particular to consider their distribution and size on the island's area. Knowing the area affected by oil pollution and the size of the economies present in this are, one can estimate the impact of the oil spill, and, as a final consequence, the cost of the oil spill relative to these economies. The sequence is as shown in Figure 4-2.

Figure 4-2. Methodology of oil spill's impact on local economies estimation



4.3.1. Stage 1: Size of oil outflow.

For a Suezmax type tanker carrying approximately 145'000 tonnes of oil cargo, the sizes of oil outflow for the Average and the Worst Case scenarios (90% of oil cargo flown out) in the cases of grounding, collision and structural failure & foundering, are summarized in the table below[12]:

[12] The details of the estimation of oil outflow under the two alternative scenarios can be obtained by the authors upon request.

Table 4-1. Spill sizes by accident cause for 145'000 tanker

Type of Accident	Average oil spill (tonnes)	Worst case scenario (tonnes)
Collision	8'175	130'000
Grounding	6'790	130'000
Structural failure and foundering	92'000	130'000

4.3.2. Stage 2: Estimation of the area involved by the oil-spill

To estimate the area affected by the oil outflow, we consider as reference a real world case, characterised by an amount of oil spilled not too different from the average case scenario of Table 4-1 (at least as far as collision and grounding are concerned) and which affected an archipelago: the Braer Spill Grounding, happened in the Shetland Island (UK) on the 5th January 1993[13].

During the 20 days following the accident, 84'700 tons of Norwegian Gullfaks crude oil were spilled out. Of that amount, 40-50% was dispersed at sea, 10-20% evaporated, 35% remained in sediments, and 1% was recovered on shoreline. Because of severe and persistent gale winds, quantities of oil were deposited on the land surface up to 3 km from the coast and almost 60 km^2 of land were reckoned to have been coated with a fine brown smear of oil at the height of the pollution event. In this case only the 1% of oil reached the shoreline, but this can be considered to be a fortunate case; in fact usually the percentage of oil that reaches the shoreline is greater.

Table 4-2 summarizes the data of the Braer accident:

Table 4-2. Baer spill scenario.

Average Grounding oil spill size (t)	84700
Shoreline	1%
Oil arrived on land (t): 1% of 84700	847
Land contaminated (km2)	60
Average Grounding oil spill size (t)	84'700
Shoreline	1%
Oil arrived on land (t): 1% of 84700	847
Land contaminated (km2)	60

For the Aegean case study scenario we assume a percentage of oil at the shoreline 10 times higher. The Aegean scenario appears then quite different from the Braer one:

Table 4-3. Aegean Sea Spill Average Case scenario.

Average Grounding oil spill size (t)	84'700
Shoreline	10%
Oil arrived on land (t): 10% of 84700	8'470
Land contaminated (km2)	600[14]

By extending linearly these quantities to the worst case grounding scenario for the Aegean Sea case study[15] the figures are:

[13] Detailed information concerning this accident has been provided by CEDRE, partner of the NEEDS project.

[14] We assume that the onshore area affected by the oil spill is directly proportional to the amount of oil that reaches the shoreline. If the oil that reaches the shoreline is 1% of the total amount of oil spilled, (thus 847 t), and contaminates a land surface of 60 km^2, then the 10% of the oil spilled (8'470 t), contaminates a land surface of x km^2, where x is calculated from this proportion: 847t:60 km^2=8470t:x.

Table 4-4. Aegean Sea Spill Worst Case scenario.

Average Grounding oil spill size (t)	130'000
Shoreline	10 %
Oil arrived on land (t): 10% of 130000	13'000
Land contaminated (km^2)	920,9[16]

4.3.3. Stages 3 and 4: Distribution and size of the local economies (tourism and fishery) on the islands' area and impacts (incident costs) estimation.

For a sake of simplicity, in order to estimate tourism and fishery sectors' sizes, we assume as a first approximation, that workers in tourism and fishery sectors are distributed homogenously over the islands. We measure the sectors' economic size in terms of sector's GDP per worker (Table 4-5).
One then needs to evaluate the number of workers in the area involved by the oil spill. To do this, the number of workers in the sector considered for each km^2 of Regional area (see Table 4-6) has been calculated.
Assuming that it will take a full year to restore normal production levels after the accident and that the whole production of that year will be lost for the sectors affected by the accident, the impact size of the oil spill on the economic sectors considered (Table 4-7) can be estimated as the product of the affected area (see Tables 4-3 and 4-4), the number of workers pertaining to the sectors considered per km^2 of regional area (Table 4-6), and the economic size of the sectors (Table 4-5):

$$I_s = A_i * \frac{W_s}{A_r} * GDP\_PC_s , \qquad (18)$$

where:

I_s = impact on local economic sector (€)
A_i = area involved by the oil spill (km^2)
W_s = number of sector's workers
A_r = regional area (km^2)
GDP_PC_s = sector's GDP per worker (€)

Table 4-5. Characteristics of local economies.

	Northern Aegean	Southern Aegean	Crete
Number of workers in Tourism sector(2003)	5'478	17'839	26'792
Number of workers in Fishery sector (2003)	2'239	3'586	1'161
Tourism Sector GDP per worker (M€)	0.03	0.05	0.03
Fishery Sector GDP per worker (M€)	0.02	0.05	0.04

[15] The hypothesis of linearly increasing impacts on the shoreline is somewhat arbitrary, because it is not granted that a larger quantity of oil will spread evenly to a longer length of shoreline; it might affect a proportionally smaller length of shoreline but deposit in thicker layers on the shore. Since modelling the dispersion of an oil spill on shore is a tremendous task, for the illustrative purposes of this paper we will content ourselves with the linear case.
[16] If the oil that reaches the shoreline is 10% of the total quantity, (thus 13000 t), the land surface contaminated is x km^2, where x is calculated from this proportion: 8470t:600 km^2=13000t:x.

Table 4-6. Workers in the involved area

	Northern Aegean	Southern Aegean	Crete
Regional Area (km^2)	3'836	5'286	8'336
Tourism workers' density (workers/km^2)	1.43	3.37	3.21
Fishery workers' density (workers/km^2)	0.58	0.68	0.14

Table 4-7. Losses (M€) for the tourism and fishery sectors in the case of Grounding

	Northern Aegean	Southern Aegean	Crete
Tourism			
Grounding average case	14.3	103.3	83
Grounding worst case	21.9	158.6	127.6
Fishery			
Grounding average case	12	21	2.6
Grounding worst case	18.4	32.2	4

This is of course only a first, rather crude approximation of the economic damages to fisheries and tourist activities after an oil spill has occurred in the Aegean.

A first way to refine these estimates would be to compute more precisely the amount of time during which the affected sectors must remain inactive. We leave this for further research[17].

In this case study we prefer to focus on another refinement: more precisely, we consider a differentiated distribution of the impact at different distances from the oil outflow. In fact, it is realistic to think that areas closer to the accident are also those most subject to the damages provoked by the oil spill. In order to incorporate this refinement into the analysis (see Figure 4-3 and Table 4-8), the area around the oil spill has been divided into three sub-areas: the first, the smallest, but nearest to the spillage point, sustains the greatest per capita damage (in proportion, greater number of workers involved and greater impact), the third, the largest, but the farthest away from the spillage point, sustains the smallest per capita damage (in proportion, smaller number of workers involved and smaller impact). The shares of the damage and the relative size of the three groups are of course chosen rather arbitrarily, for illustrative purpose only.

Table 4-8 Diversification of oil spill impacts

Land area	Workers in Tourism or Fishery sector	% involved	% of oil spill impact
Area 1	**Group 1**	**0.2%**	**10%**
Area 2	**Group 2**	**9.1%**	**45%**
Area 3	**Group 3**	**90.7%**	**45%**
	Total	**100%**	**100%**

The number of workers in the tourism and fishery sectors affected by the oil spill (Tables 4-9 and 4-10) and its impacts on these sectors are thus differentiated, as reported in Table 4-18, which collects average losses for the regions and sectors considered.

[17] Another topic is the amount by which these damages are internalised, by means of compensation payments from the ship owners and/or insurance. The legal intricacies of this subject suggest to leave aside the topic, along with the consideration that , *in any case*, the externality must be somehow assessed before being compensated.

Figure 4-3: Diversification of oil spill impact

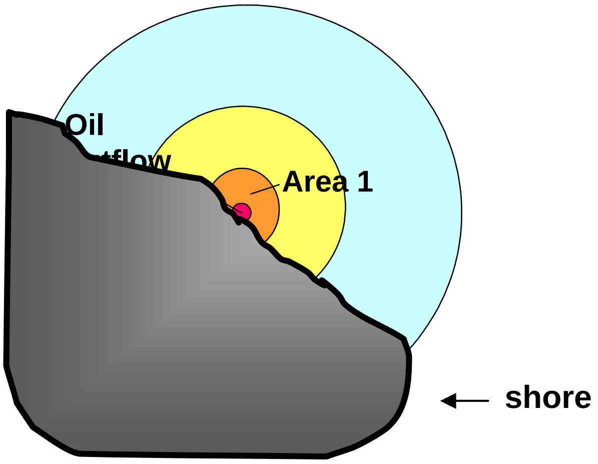


Table 4-9. Number of tourism workers involved at different distances from the oil spill

	Northern Aegean	Southern Aegean	Crete
Group 1	11	36	54
Group 2	498	1'623	2'438
Group 3	4'969	16'180	24'300
Total	5'478	17'839	26'792

Table 4-10. Number of fishery workers involved at different distances from the oil spill

	Northern Aegean	Southern Aegean	Crete
Group 1	4	7	2
Group 2	204	326	106
Group 3	2'031	3'253	1'053
Total	2'239	3'586	1'161

The expected value of the losses based on the probability assessments of Section 3 are given at the bottom of Table 4-18. However, in order to give a complete summary of these losses, we need first to bring the damages to the natural environment into the picture. This is dealt with in the following sub section.

4.4. Evaluation of the damages to the natural environment

The estimation of the damages caused to a natural environment by an accident generated by human activities is not a straightforward task. A fundamental difficulty is that environmental goods have both use and non-use values for the public and therefore an important share of their attributes do not have a market[18], and hence a directly observable price. One of the most developed methods to

[18] A somewhat related difficulty is the inherent arbitrariness in selecting the group of agents for whom the damages to a particular environment is relevant. In the case of the non-use value of an environmental good, potentially a fraction of the whole world population, irrespective of the place of residence, can be negatively affected by the fact that a valuable environment has been damaged. In any CVM study however, for practical feasibility reason it is necessary to limit the evaluation to a sample extracted from a meaningful group of individuals.

attach an economic value to a natural environment, and thus to the damages sustained by the environment itself, is the Contingent Valuation Method.
To the best of the authors' knowledge, a CVM study for evaluating the consequences of an oil spill on the environment of the area under scrutiny has not yet been carried out. Performing a full CVM evaluation for evaluating the consequences of an oil spill on the natural environment of the Greek Aegean Islands was beyond the scope (and the resources) of our project.
What can be attempted however is to evaluate to which extent the results of other CVM studies on oil spill damages can be transferred to the Aegean case, through a well established technique by the name of *Benefit Transfer Methodology*.
For this case study, we use as a reference the results of Van Bierylíet et al. [33], the only Contingent Valuation study available which evaluates the damages of an oil spill on an European Coast.
This paper offers an economic assessment of the loss on non-use values resulting from different oil spill scenarios along the Belgian Coast. The study is based on the information gathered through a telephone interview survey carried out in 2001 over a sample of 571 Belgian households.
The interested Reader is referred to [33] for the details of this study. In short, respondents were confronted with the certain perspective of being subjected to the obligation of paying an a amount of money in order to set up a prevention system that would neutralize the effects of an oil spill on the Belgian coast. The precise disaster and prevention scenarios submitted to the evaluation of each respondent were randomly chosen between three alternative scenarios, corresponding to increasing levels of severity of the accident.
In order to apply the results of [33] to our case study, we perform a very rough Benefit Transfer exercise, leaving more refined applications of these techniques to further research. Our aim here is simply to derive a value for the environmental damages caused by an oil spill as the one considered in this case study which can be reasonably applied to the population of the Greek Aegean Islands. To this aim we assume that the two most relevant sources of difference between the Belgian oil spill scenario(s) and the Greek ones boil down to two key characteristics of the Belgian and the Greek populations: their number and their income. For the rest, we very crudely assume, as a first approximation, that one meter of Belgian shore is environmentally speaking perfectly substitutable with one meter of Greek Aegean shore, at least in the eye of the inhabitants of their respective countries (in other words, we assume that Belgian and Greek tastes and preferences are extremely similar when it comes to marine environment). Therefore we use as pivot variables for the transfer the Belgian and Greek GDPs and populations: assuming that Belgian and Greek populations only differ for these two characteristics, we can rescale Belgian Willingness To Pay (WTP) to preserve the coast from the consequences of an oil spill, in such a way to obtain a crude " Greek" WTP for the preservation of the Greek equivalent of such coast.
In [33] two alternative ranges of WTP were computed depending on whether protest answers were included in the computation, where protest answers are those expressed by survey's respondents who were not prepared to pay any amount in any scenario proposed (their WTP was always equal to 0, see Table 4-11). For the aims of this case study, it has been decided to consider the WTP computed in [33] by excluding protest-answers. The higher WTP range was thus selected.

Table 4-11. Belgian study's results for 2001 (million €).

	Total WTP (min)	Total WTP (max)
Protest answers excluded	492	606
Protest answers included	375	476

Albeit very simple, our benefit transfer exercise requires a few steps in order to be performed. First, the WTP in [33] for 2001 must be transformed into per capita values for 2004. To calculate Belgian

WTP per capita for 2004 (see Table 4-13), Belgian GDP growth and Belgian Population have been used (see Table 4-12)[19].

Table 4-12. Belgian GDP and Population.

	2001	2002	2003	2004
GDP (Bln €)	254.1	261.1	268.5	283.5
GDP per capita (Mln. €)	0.025	0.025		0.027
GDP growth %	0.7	0.9	1.3	2.7
Population (Mln.)	10.26	10.31		10.4

Table 4-13. Belgian WTP (€) for 2004 (case of protest answer excluded).

	WTP min per capita	WTP max per capita
Protest answers excluded	52.1	64.2
Protest answers included	39.7	50.4

Next, Belgian per capita WTP had to be translated into per capita WTP for each of the three Greek regions considered. In order to calculate WTP per capita for Greece in 2004 (see Table 4-15), Belgian per capita WTP was rescaled using the ratio of Belgian per capita GDP to its equivalent in each of the Greek regions. The relevant data are reported in Table 4-14 below.

Table 4-14. Greek Regions' GDP and Population.

	Northern Aegean	Southern Aegean	Crete
GDP (2004) M€	2'873	4'701	8'489
GDP per capita (€)	14'463	16'142	14'647
Population (2004)	206'000	302'000	601'000

Table 4-15. Greek Regions WTP per-capita for 2004 (case of protest answer excluded).

	Northern Aegean			Southern Aegean			Crete		
	WTP min (euro)	WTP max (euro)	WTP average value (euro)	WTP min (euro)	WTP max (euro)	WTP average value (euro)	WTP min (euro)	WTP max (euro)	WTP average value (euro)
Protest-answers excluded	28	34		31	38		28	34	
Protest-answers included	21	27	24	24	30	27	21	27	24

[19] [35]

Table 4-16. Greek Regions WTP for 2004 (case of protest answer excluded).

	Northern Aegean			Southern Aegean			Crete		
	WTP min (M€)	WTP max (M€)	WTP average value (M€)	WTP min (M€)	WTP max (M€)	WTP average value (M€)	WTP min (M€)	WTP max (M€)	WTP average value (M€)
Protest-answers excluded	5.69	7.01		9.32	11.48		16.83	20.73	
Protest-answers included	4.34	5.51	4.93	7.10	9.02	8.06	12.83	16.28	14.55

Greek Total WTP for 2004 can be estimated multiplying Greek WTP per-capita by Greek Regions' populations (see Table 4-18).
To estimate the damages caused by our oil spill scenario on Greek Aegean Islands' natural environment (see Table 4-17), it has been considered, as *average case damage*, the Greek total WTP average value. As *worst case damage*, instead, the value proportional to the expected cost to the land contaminated in the worst case has been calculated as follows:

$$D_{WC} = D_{AC}\frac{A_{WC}}{A_{AC}} \quad (19)$$

Where: D_{AC} = average case damage
A_{AC} = average case contaminated area (600 km^2)
W_{AC} = worst case damage
A_{WC} = worst case contaminated area (920,9 km^2).[20]

This completes the benefit transfer exercise. The computed total WTPs for the three Aegean regions are reported in Table 4-17 below.

Table 4-17. Greek Regions WTP for 2004 (case of protest answer excluded).

	Northern Aegean	Southern Aegean	Crete
ENVIRONMENT			
Grounding average case	4.9	8.1	14.6
Grounding worst case	7.6	12.4	22.3

Also in the case of estimation of natural environment impacts, the more refined approach of differentiating the impacts, and hence the damages, according to the distance from the oil outflow, can be applied. The last three columns of Table 4-18 split the WTPs of Table 4-17 among three different groups according to the procedure described in paragraph 4.3.1. The expected costs, based on the probabilities of the events, are given in the last row of the table.
Since for the first and second group the chances that the damages are higher than the reference income levels are significant, and since the utility function is not defined for negative values of the argument and tends to minus infinity for values of the argument close to zero, we assumed a lower bound for the impacts of the oil spill on individual budgets. More precisely we assumed that, even if the oil spill would deprive the affected individuals of their main source of income for a whole year,

[20] The area affected by the outflow is again the one estimated using as reference the Braer spill (sub-section 4.3.3).

they could always count on the equivalent of one month's earnings (alternative income, formal or informal aid etc.) to withstand this severe change in their economic situation.

4.5. Risk aversion and lay risk estimation results.

Risk Aversion and Lay Risk methodologies have been applied for each region and each sector considered (Tourism, Fishery and Natural Environment). Using the probabilities of accident causes reported in Table 2-1, the monetary values of the damages to the environment just computed, and the power function[21] with $\gamma = 0$, $\sigma = 1.2$, one can compute the risk premiums following the procedure described in Section 4. To recall briefly, the risk premium, expressing the willingness to pay of the individuals in order to avoid being subjected to the risk of the accident under scrutiny, can be computed as the difference between the *cost of the accident with risk* (the loss of utility expected from the accident for a risk averse individual) and the *cost of the accident without risk* (the expected value of the damage, or the loss of utility expected from the accident for a risk neutral individual).

Table 4-18. Damages for Tourism, Fisheries and the Natural Environment, diversified by impact group, (M€, weighted average across incident types).

		Tourism			Fisheries			Natural Environment		
		N. Aegean	S. Aegean	Crete	N. Aegean	S. Aegean	Crete	N. Aegean	S. Aegean	Crete
Group 1	**average case**	1.4	10.3	8.3	1.2	2.1	0.3	0.5	0.8	1.5
	worst case	2.2	15.9	12.8	1.8	3.2	0.4	0.8	1.2	2.2
Group 2	**average case**	6.4	46.5	37.4	5.4	9.4	1.2	2.2	3.6	6.5
	worst case	9.9	71.4	57.4	8.3	14.5	1.8	3.4	5.6	10.1
Group 3	**average case**	6.4	46.5	37.4	5.4	9.4	1.2	2.2	3.6	6.5
	worst case	9.9	71.4	57.4	8.3	14.5	1.8	3.4	5.6	10.1
Total	**average case**	14.3	103.3	83.1	12.0	21.0	2.6	4.9	8.1	14.6
	worst case	21.9	158.6	127.6	18.4	32.2	4.0	7.6	12.4	22.3
	Expected costs (€)	1485.6	10756.0	8653.9	1249.2	2180.6	271.9	512.6	838.7	1514.6

Table 4-19 reports the results of the risk aversion assessment for the three sectors considered and under the assumption of differentiated impacts. Note that the values reported in Tables 4-19- 4-21 are weighted averages of the risk premiums computed for each cause of accident, where the weights are the shares reported in Table 2-1. Although, in this case study, the damages faced by the

[21] For economy of space, we do not report here the results obtained with the power function with $\gamma = 0.5$; they are very similar to those reported in this section. The results obtained under the assumption of logarithmic utility function appear in the sensitivity analysis with $\sigma = 1$.

individuals if an oil spill takes place are the same whatever the cause of an oil spill, probabilities of occurrence are not, and hence expected damages, expected utility losses and risk premiums differ across the three causes of accident considered. We report only the weighted averages in order to give an overall idea of the magnitudes of the results; detailed figures for grounding, collision and structural failure and foundering can be obtained from the authors upon request.

Table 4-19. Risk premiums (€) of Tourism Sector (differentiated impact).

	Northern Aegean		Southern Aegean		Crete	
	risk premium	fraction of expected costs	risk premium	fraction of expected costs	risk premium	fraction of expected costs
Tourism						
Total Group 1	59.5	351.1%	424.3	251.1%	538.3	251.1%
Total Group 2	1’286.2	191.1%	3’347.7	68.4%	1’221.7	31.2%
Total Group 3	34.5	5.1%	178.3	3.7%	89.4	2.3%
Total	1’380.2	100.3%	3’950.2	39.7%	1’849.4	23%
Fishery						
Total Group 1	48.2	351.1%	82.9	251.1%	22.8	351.1%
Total Group 2	800	145%	743.2	74.8%	40.5	32.9%
Total Group 3	30.2	5.4%	37.5	3.8%	2.9	2.4%
Total	878.4	77.8%	863.7	42.8%	66.2	26.3%
Environment						
Total Group 1	2.8	5.5%	4.6	5.5%	8.4	5.5%
Total Group 2	1.2	0.5%	1.9	0.5%	3.5	0.5%
Total Group 3	0.1	0.1%	0.2	0.1%	0.3	0.1%
Total	4.1	0.8%	6.8	0.8%	12.2	0.8%

In Tables 4-20 and Table 4-21 we redo the same evaluation applying Lay Risk probabilities 20 times (respectively, 100 times) higher than expert probabilities using the same function as above and the same scenario.

Table 4-20. Lay Risk assessment of Risk premiums (€)-differentiated impact, expert probabilities x 20.

	Northern Aegean		Southern Aegean		Crete	
	risk premium	fraction of expected costs	risk premium	fraction of expected costs	risk premium	fraction of expected costs
Tourism						
Total Group 1	845.6	249.8%	8’436.3	249.8%	10’704	249.8%
Total Group 2	25’594.8	190.2%	66’747.9	68.2%	24’370.2	31.1%
Total Group 3	689.3	5.1%	3’558.1	3.7%	1’785.1	2.3%
Total	27’129.7	138.3%	78’742.4	44.9%	36’859.2	24%
Fishery						
Total Group 1	685.7	249.8%	1’649.3	249.8%	454.2	349.8%
Total Group 2	15’932.5	144.4%	14’816.4	74.5%	807.1	32.8%
Total Group 3	602.5	5.3%	749.3	3.8%	58.2	2.4%
Total	17’220.7	79.5%	17’215.1	49.3%	1’319.6	27.3%
Environment						
Total Group 1	56.5	5.50%	92.5	5.50%	167	5.5%
Total Group 2	23.7	0.51%	38.7	0.51%	6.3	0.05%
Total Group 3	2.4	0.05%	3.9	0.05%	7	0.05%
Total	82.6	0.84%	135.1	0.84%	180.4	0.62%

Table 4-21. Lay Risk assessment of Risk premiums (€)-differentiated impact, expert probabilities x 100.

	Northern Aegean		Southern Aegean		Crete	
	risk premium	fraction of expected costs	risk premium	fraction of expected costs	risk premium	fraction of expected costs
Tourism						
Total Group 1	4'126.9	244.4%	41'174.7	244.4%	52'242.2	244.4%
Total Group 2	125'299.2	186.5%	329'432.1	67.4%	120'530.5	30.8%
Total Group 3	3'414.7	5.1%	17'628.6	3.6%	8'845.1	2.3%
Total	132'840.8	135.3%	388'235.4	44.4%	18'617.7	23.7%
Fishery						
Total Group 1	3'346.5	244.4%	8'049.7	244.4%	2'232.4	344.4%
Total Group 2	78'240.4	142.1%	73'102.2	73.6%	3'991.6	32.5%
Total Group 3	2'984.9	5.3%	3'712.5	3.8%	288.5	2.4%
Total	84'571.8	78.3%	84'864.3	48.7%	6'512.5	27%
Environment						
Total Group 1	280.1	5.45%	458.3	5.45%	827.5	5.45%
Total Group 2	117.4	0.51%	192	0.51%	31.4	0.05%
Total Group 3	11.7	0.05%	19.2	0.05%	34.6	0.05%
Total	409.1	0.84%	669.4	0.84%	893.5	0.62%

Tables 20-21 highlight a few interesting facts. First, allowing for lay risk probabilities increases noticeably the willingness to pay of individuals to reduce their exposition to risk in absolute terms for the tourism and fishery sectors. This increase is almost directly proportional to the increase of the probabilities attached to the accident. Secondly, assuming higher accident probabilities does not change much the overall ratio of risk premiums to the expected cost of an accident; it does however increase this ratio for the most vulnerable groups. Both these features derive from the properties of the utility function used to evaluate risk aversion. Thirdly, both in absolute and in relative terms, risk premiums are modest for the case of direct damages to the environment [22]. This is mainly due to the magnitude of the damages assumed for this category of impacts. However, for the damages to economic activities, risk premiums are much more substantial. Allowing for differentiated impacts clearly highlights how the discomfort of even a small number of potentially severely affected individuals can account for a substantial welfare loss, especially if lay risk evaluation is taken into consideration. For example, in the case of tourism in Southern Aegean, the risk premiums for groups 1 and 2, who represent only 10% of the workforce, can be as much as €0.56 million in the case of Structural Failure and Foundering (when averaged out with the corresponding values for the other two causes of accident, this figure decreases to €0.37 million[23]). In any case this is more than twenty times the risk premium of the remaining 90% of the workforce.

4.5.1. Sensitivity Analysis

Sensitivity analysis has been performed in order to check the robustness of the methodologies applied. Estimations have been made considering different power functions with γ=0 and σ variable. Table 4-22 reports the results of such analysis for the Northern Aegean region[24]. The last column in particular gives the total risk premium for the whole population of the region. These

[22] Recall that the figures given in Tables 4-19 - 4-21 are total values for all individuals in each group.
[23] This figure is the sum of the risk premiums of Groups 1 and 2 for Southern Aegean tourism in Table 4-21.
[24] For the case of γ=0 and σ=1.2 the values reported in Table 4-22 coincide with those reported in Table 4-21, for the Northern Aegean.

values take into account lay risk probabilities, differentiated impacts among three population groups, and sum up the damages to fisheries, tourism and the environment[25].

Table 4-22. Sensitivity Analysis, lay risk assessment (expert probabilities X 100) of Northern Aegean Tourism sector.

σ	Risk Premium (€) Group 1	Risk Premium (€) Group 2	Risk Premium (€) Group 3	Total Northern Aegean	
				Risk Premium (€)	fraction of expected costs
1*	2834	78'968	2829	84'632	62%
1,2**	**4127**	**125'299**	**3415**	**132'841**	**97%**
1,5	7049	293'144	4305	304'498	218%
2	16'415	1'492'953	5823	1'515'191	1066%
4	108'547	7'977'905	12345	8'098'797	6743%

*** the function with σ = 1 is the logarithmic utility function**
**** this is the value of σ used in the computations.**

Note that in Table 4-22, realistic degrees of risk aversion can be related to values of σ not greater than 2. Thus the last row of the table is for comparison purposes only. The message of this table is thus the following: taking extremely concave utility functions, risk premiums may explode, while, for realistic values, there is a moderate to large increase in risk premiums. It is thus important to calibrate correctly the utility function used for the evaluations.

These results point to a relative robustness of the methodology in terms of the choice of the utility function, *for events with a probabilistic structure such as the one analyzed here.* In other words, for oil spills, the degree of risk aversion embedded in the utility function used to evaluate the probabilistic externalities is important for the final results and it is thus important to stick to realistic values of this parameter.

5. Conclusion

This paper has developed a methodology to assess probabilistic externalities caused by oil transportation by tanker. The Aegean Islands case study has provided an example of how the evaluation of the probabilistic externalities caused by an oil spill can be performed using a more refined and realistic methodological framework than the usual risk neutral Expert Expect Damage assessment approach.

The value of this exercise is, in the opinion of the authors, more in showing the feasibility of a more refined approach than in the actual numerical results. It is however interesting to discuss briefly the outcome of the analysis performed.

In the Aegean Islands' case, it is apparent that the computed risk aversion premiums for oil spill accidents are negligible in the case of damages to the natural environment, but they cannot be overlooked when damages to economic activities are analysed and lay risk evaluation is taken into account. In the case of the damages to the environment, this result arises because of the low magnitude of the damages involved (both use and non-use) and by the low probabilities associated to the negative outcomes of the lottery modelled. In other words, the maximum damage that each inhabitant of Aegean Island (that is, per capita damages) may actually suffer from seeing their

[25] The results for the other two regions are qualitatively similar and are not reported here for economy of space.

coastal environment damaged by an oil spill of the kind considered (which is, by the way, a reasonably serious accident) is much lower than what they would suffer by, say, bumping their car while waiting for the green light at a crossroad. The story is very different for economic activities, where small groups can be very severely affected in their ability to generate income. This generates a strong dislike for the risk they are exposed to and consequently they may be prepared to pay substantial amounts to avoid it[26]. The following conclusions could be drawn from the case study:

- The costs of oil spills (in terms of losses for the tourism sector, fisheries and damages to the natural environment) in the Aegean are estimated at around € 405 million, in the case of a worst case oil spill, and around € 264 million, in the case of a 'typical' spill.
- The 'expected value' of these losses – i.e. the costs referred to above times the associated probabilities is € 22'662 for a typical spill and € 1935 for a worst case oil spill.
- This value is based on the expert probabilities. If we take indicative lay estimates of the probabilities of the accidents, which could be as much as 100 times higher, the expected costs will also increase by a factor of 100.
- The risk premiums on these expected costs are not negligible when measured as a percentage of expected costs for tourism and fisheries (on average about 90%, 40% and 23% in Northern Aegean, Southern Aegean and Crete respectively, , but up to 350% for particularly affected groups); by contrast, they are quite small for the case of damages to the natural environment (on average around 0.8% in all regions). Assuming higher accident probabilities does not change much the overall regional ratios of risk premiums to their correspondent expected costs for a given accident; it does however increase these ratios for the most vulnerable groups, when risk premiums are broken down for different impact groups. Also, the absolute values of risk premiums increase considerably assuming lay probabilities.

The assessment of the probabilities of an oil spill requires the knowledge of both general causal factors and of factors that are specific of the site where the accident takes place and of the ship involved in the accident. Although it is possible to portrait the general shape of the causal links that may lead to an oil spill, case by case evaluation is necessary in order to compute specific probability values.

On the other hand, once these probabilities have been computed and the relevant impacts and burdens have been assessed, introducing risk aversion and lay risk evaluation is a relatively straightforward task, although careful calibration of the utility function must be performed in order to arrive at realistic values. The impact of these refinements on the final monetary evaluation of the damage depends however again on the characteristics of the site where the oil spill takes place, due to the spatial variability of probabilities, impacts and burdens. Future work is needed to assess the lay probabilities more carefully and to examine more sites/routes to increase our understanding of accident costs of oil transportation by sea.

[26] Direct comparability between risk premiums for losses to economic activities and risk premiums for damages to the natural environment is not fully possible, due to the fact that their evaluation is based on different initial levels of income. This is one of the issues currently tackled by our ongoing research.

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