How safe is safe enough?

The government's response to industrial and flood risks

Proefschrift

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Abstract

Disasters can never be completely ruled out. The Dutch national government has therefore committed itself to the concept of risk rather than the false promise of absolute safety. The objectives of this study were to evaluate current regulatory practices in the domains of industrial and flood safety in the Netherlands, and to formulate proposals for improvement. The outcomes of such an endeavour obviously depend heavily on the chosen yardstick to distinguish between superior and inferior policy alternatives. Throughout this thesis, social improvements have been defined in a way that is consistent with the approach followed in societal cost-benefit analyses.

The main conclusions and recommendations are listed below. Each chapter ends with a more detailed set of conclusions. It should constantly be kept in mind that all conclusions and policy recommendations rest on a consequentialist ethic, i.e. an ethic that considers only the outcomes of decision-making. Different approaches might yield vastly different results. But understanding where a cost-benefit framework does *not* get us is arguably just as important as understanding where it does. Because the study of risk and regulation requires a strongly multidisciplinary effort, this dissertation draws upon both the social and natural sciences. It is exactly the attempt to bring together various disciplines that, I hope, will make this thesis an interesting and thought-provoking read.

1. Risk appraisal is a value-laden activity. No scientist can rightfully claim to possess superior knowledge about the risks that ought to be acceptable to all. But this need not lead to mindless relativism. Scientists can assist decision makers by clarifying problems, by pointing to key variables and by illuminating trade-offs. (chapter 1)

2. Risk regulation is a balancing act. Neither too much nor too little risk or regulation comes to the benefit of society. Risk should not be singled out as the only factor driving decisions. (chapter 2, chapter 8)

3. Under the consequentialist utilitarian ethic that underlies this thesis, a necessary condition for government intervention lies in the presence of market failures. These include negative externalities (third party risks), public goods (the provision of flood protection), and imperfect information. (chapter 2)

4. Although market failure is a necessary condition for government intervention, it is by no means a sufficient one. The drawbacks of an intervention could outweigh its gains. (chapter 2)

5. Liability rules, taxes, subsidies and other forms of government intervention should not be treated in isolation as their consequences might overlap. The stringency of new regulations should depend on the liability rules and regulations that have already been put in place. (chapter 3)

6. The polluter pays should not be used as a general principle underlying risk regulation. This is because it does not always lead to the most cost-effective measures being taken. (chapter 3)

7. The ALARA-principle (As Low As Reasonably Achievable) is often interpreted as a continuous effort to reduce risks. While this interpretation is broadly reasonable in case of technological progress and/or intensifying demands for a safe society, it would sometimes be reasonable to allow risks to increase. (chapter 3)

8. The advice to not construct flood defences because they worsen rather than reduce flood risks is, at least for large parts of the Netherlands, incorrect. Firstly, the argument presupposes morphological conditions that seem highly unrealistic. Secondly, a delta without dikes would unlikely provide protection against the low-probability, extreme events that the Dutch flood defences have to withstand. Finally, regular flooding would unlikely have been compatible with past economic growth. (chapter 4)

9. The Dutch industrial and flood safety policies are both firmly risk-based. But while the FN-criteria that are used in the Dutch major hazards policy are averse to larger numbers of fatalities, a linear value function for fatalities is used in the cost-benefit analyses for the Dutch flood defences. (chapter 5)

10. Decision makers should be aware that it will often be troublesome to compare the reported financial balances of different cost-benefit studies in the field of health, safety, and the environment as the assumptions underlying these cost-benefit analyses sometimes diverge widely. In practice, a relatively high reported net present value need not imply that the project actually outperforms other public investments as there might be considerable differences between underlying assumptions. (chapter 6)

11. Pressing for uniform societal risk criteria is to confuse equity and efficiency: societal risk criteria are related to efficiency rather than equity. Different societal risk criteria should ideally apply to cases in which the marginal costs of risk reduction differ considerably from the average case. (chapter 7)

12. Although it might sometimes be wholly reasonable to act prior to proof of harm, many interpretations of "the" precautionary principle imply a number of biases that cannot be defended on utilitarian grounds. Politicians and policymakers are therefore advised to refrain from using the popular (yet ambiguous) precautionary principle as a guide for risk decision making. (chapter 8)

13. The safety chain (proaction, prevention, preparation, repression) is not as weak as its weakest link. It is at least as strong as the strongest link. This has important implications for the efficient allocation of resources: underperforming links need not always be strengthened. (chapter 9)

14. The definition of an optimal level of disaster preparedness should encompass a probabilistic element: the expected frequency with which response capacity is allowed to fall short. Regional differences in preparedness, and differences between the preparedness of different emergency services (police, fire brigades, medical aid) can be wholly justifiable on utilitarian grounds. (chapter 9)

15. Concentration, moral hazard on the part of the government, and risk perception are important obstacles to the insurability of large-scale floods in the Netherlands. An insurance arrangement in which the national government plays a dominant role would be a viable and efficient means to resolve the uninsurability of large-scale floods in the Netherlands. (chapter 10)

16. The interplay between insurance and prevention should not be overlooked. When full insurance against the actuarially fair premium is unavailable, the cost of risk bearing will typically exceed expected loss. In that case, it would be incorrect to optimize failure rates on the basis of risk-neutral cost-benefit studies. The risk neutral cost-benefit analyses that are used to calculate economically optimal failure rates for the Dutch primary flood defences implicitly assume full and fairly priced insurance. The introduction of an insurance program thus cannot be used as an excuse for not meeting flood safety standards or as a justification for a lower standard of protection. (chapter 11)

R.B. Jongejan
August 2008

Samenvatting

Rampen kunnen nooit geheel worden voorkomen. De Nederlandse overheid heeft zich daarom gecommitteerd aan risicobeheersing in plaats van de valse belofte van perfecte veiligheid. Deze studie had als doel om het huidige Nederlandse beleid ten aanzien van externe veiligheid en overstromingsveiligheid te evalueren, en voorstellen voor verbetering te formuleren. De resultaten van een dergelijke exercitie worden uiteraard sterk bepaald door de wijze waarop onderscheid wordt gemaakt tussen superieure en inferieure beleidsalternatieven. In deze studie zijn maatschappelijke verbeteringen gedefinieerd op een wijze zoals dat ook in kosten-batenanalyses gebruikelijk is.

De voornaamste conclusies en aanbevelingen zijn in onderstaande opsomming weergegeven; elk hoofdstuk eindigt met een meer gedetailleerde set conclusies. Men dient zich constant te realiseren dat alle conclusies en aanbevelingen zijn gebaseerd op een consequentialistische ethiek; een ethiek die zich enkel richt op de uitkomsten van besluitvorming. Andere benaderingen zouden tot sterk verschillende inzichten kunnen leiden. Maar het doorzien waar een welvaartseconomische benadering ons *niet* toe zou brengen is wellicht minstens zo belangrijk is als het doorzien waar wel. Omdat een analyse van risico en risicobeleid een sterk multidisciplinaire benadering vraagt, is een beroep gedaan op zowel de natuurwetenschappen als de sociale wetenschappen. Het proefschrift beoogt verschillende disciplines op een dusdanige wijze met elkaar te verbinden dat een helder beeld ontstaat van de strategische keuzen die ten grondslag liggen aan een gedegen risicobeleid.

1. De beoordeling van de aanvaardbaarheid van risico's is inherent waardegeladen. Het is onmogelijk om op wetenschappelijke gronden vast te stellen welke risico's aanvaardbaar zouden moeten zijn. Dit hoeft echter niet te leiden tot onbezonnen relativisme. Wetenschappers kunnen besluitvormers wel degelijk ondersteunen door het verhelderen van vraagstukken, door het aanwijzen van belangrijke variabelen, en door het inzichtelijk maken van de gevolgen van besluiten. (hoofdstuk 1)

2. Het formuleren van risicobeleid is een balanceeroefening. Noch teveel, noch te weinig risico komt de samenleving ten goede. Besluiten dienen niet te worden gebaseerd op risico's alleen. (hoofdstuk 2, hoofdstuk 8)

3. Uitgaande van het gehanteerde welvaartseconomische perspectief is marktfalen een noodzakelijke voorwaarde voor overheidsinterventie. Het gaat daarbij zowel om negatieve externaliteiten (externe risico's), publieke goederen (waterkeringen), als imperfecte informatie. (hoofdstuk 2)

4. Hoewel marktfalen een noodzakelijke voorwaarde is voor overheidsinterventie, is het geen voldoende voorwaarde. De kosten van interventie kunnen de baten overstijgen. (hoofdstuk 2)

5. De effecten van het aansprakelijkheidsrecht, regels, belastingen, subsidies, en andere vormen van overheidsingrijpen overlappen veelal. Ze dienen dan ook in samenhang te worden beschouwd. Zo dient de strengheid van nieuwe regels afhankelijk te zijn van de mate van afschrikking die door reeds aanwezige regels is gecreëerd. (hoofdstuk 3)

6. De vervuiler betaalt dient niet altijd als beslisregel te worden gehanteerd omdat het in sommige gevallen kan leiden tot een inefficiënte aanwending van middelen. (hoofdstuk 3)

7. Het ALARA-principe (As Low as Reasonably Achievable) wordt vaak geïnterpreteerd als een continue inspanning om risico's te reduceren. Deze interpretatie is redelijk in geval van technologische vooruitgang en/of een toenemende vraag voor een veilige samenleving. In sommige gevallen kan het echter redelijk zijn om risico's te laten toenemen. (hoofdstuk 3)

8. Het advies om af te zien van de aanleg van waterkeringen omdat deze overstromingsrisico's doen toenemen in plaats van afnemen, is, althans voor grote delen van Nederland, onterecht. Ten eerste veronderstelt de stelling onrealistische morfologische condities. Ook zou een delta zonder waterkeringen weinig bescherming bieden tegen de zeldzame, extreme gebeurtenissen waarvoor de Nederlandse primaire keringen het achterland beschermen. Ten slotte is het onwaarschijnlijk dat de afgelopen economische groei verenigbaar zou zijn geweest met regelmatige overstromingen. (hoofdstuk 4)

9. Het Nederlandse externe veiligheidsbeleid en het overstromingsveiligheidbeleid zijn beide risicogebaseerd. De FN-criteria die worden gehanteerd in het Nederlandse externe veiligheidsbeleid zijn echter avers tegen grotere aantallen slachtoffers, terwijl in de kosten-batenanalyses voor de Nederlandse primaire waterkeringen lineaire waarderingsfuncties voor slachtoffers worden gehanteerd. (hoofdstuk 5)

10. Besluitvormers dienen zich ervan bewust te zijn dat het veelal moeilijk is om de gerapporteerde financiële balansen van kosten-batenanalyses op het gebied van gezondheid, veiligheid en milieu onderling te vergelijken. In de praktijk hoeft een project met een relatief hoge gerapporteerde netto-contante waarde door verschillende aannamen niet daadwerkelijk beter te presteren dan andere projecten. (hoofdstuk 6)

11. Het aandringen op uniforme groepsrisicocriteria komt neer op het verwarren van efficiëntie en rechtvaardigheid (gerelateerd aan een verdelingsvraagstuk). Groepsrisicocriteria zijn primair gericht op efficiëntie. Afwijkende groepsrisicocriteria zouden idealiter moeten worden toegepast in gevallen waarin de marginale kosten van risicoreductie afwijken van het gemiddelde geval. (hoofdstuk 7)

12. Hoewel het soms geheel redelijk kan zijn om op te treden voordat een bewijs van schadelijkheid is geleverd, behelzen veel interpretaties van "het" voorzorgprincipe

een aantal vooringenomenheden die niet verdedigbaar zijn vanuit een welvaarts-economisch perspectief. Politici en beleidsmakers wordt daarom geadviseerd om geen gebruik te maken van "het" voorzorgprincipe als richtsnoer bij de beoordeling van risico's. (hoofdstuk 8)

13. De veiligheidsketen (proactie, preventie, preparatie, repressie) is niet zo zwak als de zwakste schakel: de keten is tenminste zo sterk als de sterkste schakel. Dit heeft belangrijke implicaties voor de efficiënte aanwending van middelen: slecht presterende schakels hoeven niet altijd te worden versterkt. (hoofdstuk 9)

14. De definitie van een optimaal preparatieniveau dient een probabilistisch element te bevatten: de verwachte frequentie waarmee de inzet van hulpdiensten tekort mag schieten. Regionale verschillen binnen en verschillen tussen de verschillende hulpdiensten (politie, brandweer, etc.) kunnen daarbij vanuit een welvaartseconomisch perspectief wenselijk zijn. (hoofdstuk 10)

15. Belangrijke obstakels voor de verzekerbaarheid van grootschalige overstromingen in Nederland betreffen de hoge mate van concentratie, het moreel risico van de overheid, en risicoperceptie. Een verzekeringsarrangement waarin een dominante rol is weggelegd voor de overheid zou een efficiënte oplossing zijn voor de onverzekerbaarheid van dergelijke overstromingen. (hoofdstuk 10)

16. Tussen preventie en verzekering bestaat een belangrijke relatie. Als volledige dekking tegen de actuarieel eerlijke premie niet beschikbaar is, dan overstijgen de kosten van het dragen van een risico typisch de verwachtingswaarde van de schade. In dat geval zou het onterecht zijn om faalkansen te optimaliseren op basis van risiconeutrale kosten-batenanalyses. De risiconeutrale kosten-batenanalyses voor de Nederlandse waterkeringen nemen impliciet aan dat volledige en optimaal geprijsde verzekering voorhanden is. De introductie van een verzekeringsprogramma kan dan ook niet worden aangegrepen als een excuus voor het niet halen van veiligheidsnormen, of als onderbouwing voor lagere beschermingsniveaus dan volgt uit risiconeutrale kosten-batenanalyses. (hoofdstuk 11)

R.B. Jongejan
Augustus 2008

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Chapter 1

Introduction

This chapter discusses the background of this thesis, the objectives and research questions. It also deals with the methodological and normative choices that have been made.

1.1 The government's response to risks to the public

The history of man is marked by innumerable disasters[1]. Ovidius wrote about Deucalion and Pyrrha, the sole survivors of a devastating flood ordered by Zeus. In 79 AD, a volcanic eruption of Mount Vesuvius covered the Roman city Pompeii with a thick layer of ash. Methods for risk analysis and risk management have progressed considerably over time, from the consultation of obscure oracles to the use of complex quantitative risk assessments (Covello and Mumpower, 1998). But although man has proved increasingly capable of harnessing and manipulating the forces of nature, large natural disasters are not a thing of the past. On the 29th of August 2005, a category 3 hurricane struck the Southern US Gulf coast. Wind speeds up to 200km/h ravaged the city of New Orleans and smaller coastal towns. When hurricane Katrina had passed, the suffering was not nearly over. The levy system protecting New Orleans proved no match for the storm surge and large parts of the city were flooded. Over 1400 people lost there lives.

Disasters not only have natural causes. Through his understanding of the forces of nature, man has become capable of designing technological systems with an enormous catastrophic potential. Just after midnight on April 26 1986, the world witnessed its first nuclear melt-down. Thousands suffered from the consequences of radiation exposure. More than a hundred thousand people had to be evacuated. The disaster had enormous economic and political consequences for the Soviet Union. The rise of nuclear power as the clean energy for the future had come to an abrupt halt. Nowadays, all that reminds of

[1] Throughout this thesis, the terms disaster, large-scale accident, catastrophe and crisis are used interchangeably. In crisis management literature, distinctions are often made between these various terms. Different definitions are again used by e.g. the United Nations to classify natural events.

the catastrophic disaster in Chernobyl is a stretch of deserted land and a huge concrete sarcophagus that brings testimony to one of the worst man-made accidents in history.

In 1984, an accident at the Union Carbide pesticides plant in Bhopal caused a methyl-isocyanine release. Thousands ran for their lives but never came far. In the end, about 3000 people were killed and an estimated 200.000 were seriously injured (Shrivastava, 1992). The accident sent a shockwave through the process industry. Never had a chemical accident been so severe. But despite two decades of lessons learnt, large-scale industrial accidents are not a thing of the past. On May 13 2000 for instance, a fireworks storage facility in Enschede, the Netherlands, exploded. Twenty-two people were killed. People were amazed and outraged to find out that such a hazardous factory was located in a densely populated area. The event itself was not without precedent however: explosions of gunpowder storages have left their marks on several cities in the Netherlands throughout the centuries.

Despite these alarming words, the western world has never been as safe. The many uncertainties in life have been strongly reduced and life expectancy continues to rise. But although this sounds encouraging, it seems that citizens are increasingly less willing to accept even remote probabilities of harm. Douglas and Wildavsky (1983) have suggested that the strong focus on certain risks is caused by social processes and institutions. It has even been suggested that society has become a Risikogesellschaft, or risk society, in which the distribution of risk rather than the distribution of wealth is a central theme (Beck, 2004).

In the 2003 Cleveringa-lecture at Leiden University, titled "No day without risks", Dutch vice Minister Melanie Schultz van Haegen addressed the growing public demand for a risk-free society. She discussed the impossibility of zero risk and the government's[2] limited ability to protect its citizens from harm. Rather than the false promise of absolute safety, she argued for the recognition that accidents can never be completely ruled out, a viewpoint that was already adopted by the Delta Committee[3] in the 1950s. The story that accidents cannot be prevented is however not easily told. A more consistent response to risks to the public might perhaps improve the legitimacy of risk regulation. The regulatory arrangements that exist today are generally the result of a long process of "muddling through", influenced by numerous contextual factors, historical events and pure coincidences. The 2003 report "Dealing rationally with risks" by the Netherlands Environmental Assessment Agency discussed the opportunities for a generic approach to risk appraisal (RIVM, 2003). It was turned into a cabinet decision showing the executive's commitment to this endeavour.

One of the central objectives of this thesis is to take the debate on the proportionality and consistency of risk regulation one step further. But before discussing objectives and research question, a brief introduction will be given to the two policy domains that feature so prominently in the sub-title of this thesis.

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[2] The government obviously comes in a wide variety of forms. Throughout this thesis, the term "the government" is used to refer to a body with the formal powers to make collectively binding decisions.

[3] The Delta Committee was installed after the 1953 flood to prepare a plan to protect the land from flooding and to prevent siltation.

1.2 The Dutch industrial and flood safety policies[4]

1.2.1 An introduction to the Dutch industrial safety policy

The first severe industrial accident in the Netherlands dates back to 1654 when a gunpowder storage exploded in Delft's city centre. Part of the city was destroyed and fifteen hundred people were killed. The "donderslagh", as the explosion was called, could be heard as far as Alkmaar, a city 55 kilometres away (Ale, 2005). In 1807, a ship transporting gunpowder exploded in Leiden. Over one hundred and fifty people were killed, and over two thousand were wounded. This disaster led Louis Napoleon, who ruled the Netherlands at that time, to issue an imperial decree concerning the licensing and siting of hazardous establishments. The scope of the imperial decree was widened and it was turned in a Royal Ordinance in 1814. And in 1875, at the time of the Dutch industrialization, this Royal Ordinance was turned into the Factory Law (Ale, 2005). The foundations of the present-day major hazards policy were laid by the annex Premises for Risk Management (1989) that was presented to Parliament in 1989.

The European Commission issued its first directive concerning the prevention of major industrial accidents in 1982. It was named the Seveso Directive (1982) after the Italian town Seveso where a dioxin release in 1976 had caused considerable pollution. The Seveso Directive was amended twice following a number of large-scale accidents within and outside the European Union. The Seveso Directive was then replaced by the Seveso II Directive (1996a). It covers a wide range of topics, ranging from plant safety requirements to inspection and land-use planning provisions. Because member states have had considerable freedom in implementing the directive, various types of major hazards policies can be found throughout the European Union. These can be grouped into two broad categories (after Papazoglou et al., 1998; Christou and Mattarelli, 2000): effect-based approaches (e.g. Germany, France before the Toulouse accident) and risk-based approaches (e.g. UK, France after the Toulouse accident). While effect-based approaches use reference scenarios for evaluating risk acceptability, risk-based approaches consider a wide range of accident scenarios together with their probabilities. Under the latter approach, accident probabilities are an integral and explicit part of decisions on the acceptability of risks. The Dutch major hazards policy has remained firmly risk-based ever since its foundations were laid by the annex Premises for Risk Management (1989).

The cornerstones of the present Dutch external safety policy are (i) quantitative risk analysis, (ii) the use of individual and societal risk as risk-metrics, and (iii) quantitative acceptability criteria for the evaluation of individual and societal risks (Ale, 1991; 1993; Bottelberghs, 2000). Individual risk is defined as the annual probability that an unprotected, permanently present individual dies due to an accident at a hazardous site. Individual risk criteria lay down maximum levels of individual risk. Iso-risk contours can be plotted on a map for spatial planning purposes (Figure 1). The individual risk criterion (10^{-6} per annum for vulnerable objects) was given a legal status by the External Safety Decree (2004). A permit for property developments or plant modifications is denied if

[4] The terms "industrial safety policy", "external safety policy" and "major hazards policy" are used interchangeably throughout this thesis.

vulnerable objects such as houses (more than two per hectare), hospitals or schools would then be located within the 10^{-6} contour.[5]

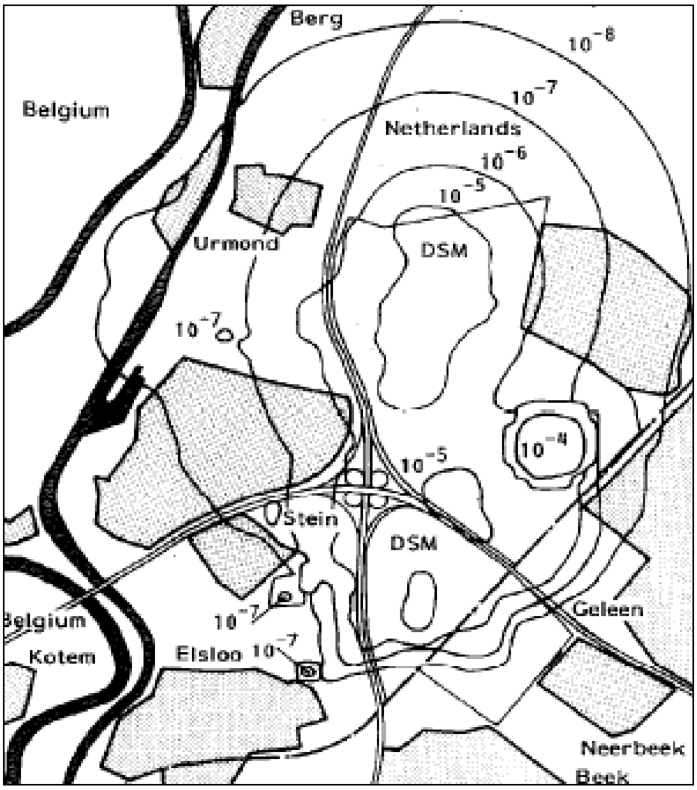

Figure 1 Individual risk contours around a hazardous site (Ale, 1991)

When individual risks are low, there could still be a chance that a single accident kills a large number of people. While a vast number of small accidents can go by almost unnoticed, multi-fatality accidents can shock a nation. Psychometric studies have indeed shown that catastrophic potential is an important factor in explaining risk perceptions (Slovic, 1987). Societal risk criteria were adopted in the Netherlands to prevent the too frequent occurrence of large-scale accidents. Societal risk is graphically represented by an FN-curve that shows the exceedance frequency (F) of the number of fatalities (N) on

[5] A death rate of 10^{-6} per year is often used as an upper limit to individual risk. Kelly and Cardon (1991) traced the origin of the widely cited 10^{-6} criterion to a cancer study by two researchers who needed a measure for "negligible risk" (in fact, they proposed 10^{-7} but the US Environmental Protection Agency later decided to use 10^{-6} instead). It was then adopted in an ever-expanding number of US health and safety regulations, and eventually spread around the globe. A death rate of 10^{-6} per year is roughly equal to 1% of the death rate of those that belong to the strongest age group.

double log scale. An FN-curve is essentially a cumulative loss distribution. The Dutch societal risk criterion of $10^{-3}/n^2$ per establishment per annum was initially developed for LPG-fuelling stations but it was later applied to all Seveso establishments. Similar societal risk criteria thus apply to hazardous establishments of different character and size.

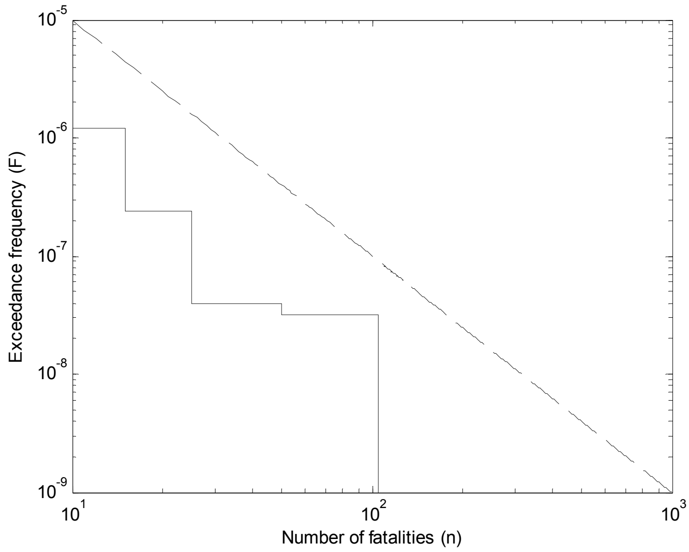

Figure 2 Fictitious FN-curve (continuous line) and the Dutch FN-criterion for hazardous establishments (dashed line)

Administrative regulation for transport safety is still in development in the Netherlands. Interim regulation for the transport of hazardous materials by road, railroad and water has been laid down by the Rnvgs, Risk standards for the transport of hazardous materials (1996). Similar to the regulations for hazardous establishments, individual and societal risk criteria are used to evaluate transport risks. The individual and societal risk criteria for the transport of hazardous materials show considerable resemblance to the criteria for establishments although the seemingly more lenient societal risk criterion for transport ($10^{-2}/n^2$ per annum) is defined per kilometre rather than per establishment.

1.2.2 An introduction to the Dutch flood safety policy

Floods, erosion, accretion and human interventions have all had a considerable impact on the Dutch landscape (Figure 3). Water boards were established centuries ago to coordinate the efforts to manage the water system. The first date back to the end of the 13th century (Schieland, 1273; Rijnland, 1286). These are in fact the oldest democratic organizations in the Netherlands (the Netherlands as a nation or country did not exist at that time) (Andeweg and Irwin, 1993). Nowadays, responsibilities for water management are divided over the national government, provinces and water boards.

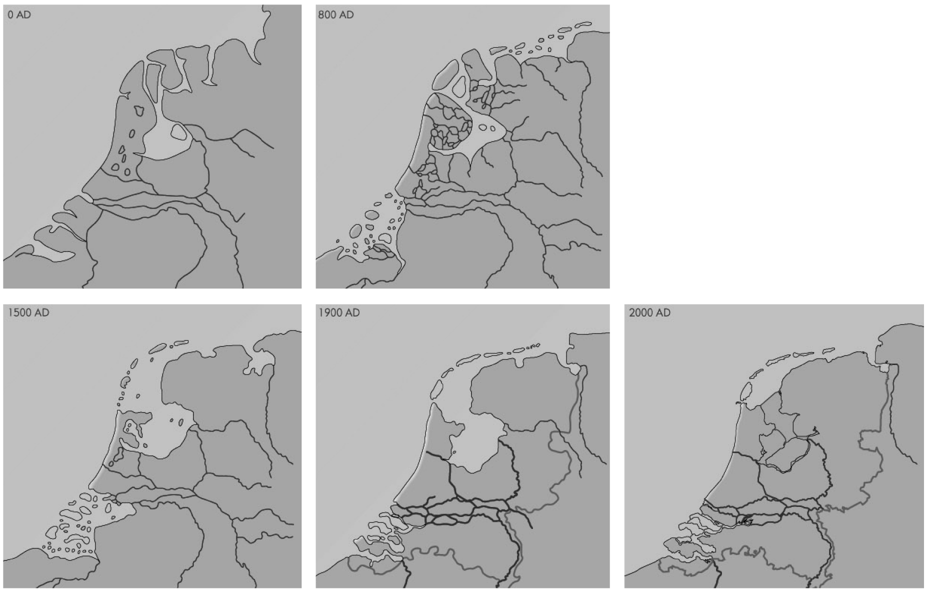

Figure 3 The face of the Netherlands at approximately 0, 800, 1500, 1900, and 2000 AD (Huisman, 2004: 34)

The rivers and sea that allowed trade to flourish proved a mixed blessing and the history of the present-day Netherlands is marked by numerous devastating floods. The last major flood dates back to 1953. On the night of January 31st and the early morning of February 1st 1953, a severe north western storm struck the Dutch coast. The levees were breached at some 150 locations. A large part of the south western part of the Netherlands was flooded and 1835 people lost their lives (Gerritsen, 2005). After this tragedy, a committee was installed to coordinate the efforts to drastically improve flood safety in the Netherlands. The so-called Delta Committee effectively laid the foundations of the present-day Dutch flood safety policy. For the first time, safety standards for flood defences were defined in terms of exceedance frequencies of water levels. Cost-benefit analysis was used to derive/rationalize these standards: the sum of the discounted investments in flood defence and the discounted expected value of future losses was minimized (Van Dantzig, 1956).

The risk-based design philosophy that was developed by the Delta Committee still forms the foundation of the Dutch flood safety policy. The Flood Defence Act (1995) ("Wet op de Waterkering") is the most important legal document concerning the mitigation of large-scale flood risks in the Netherlands. It lays down responsibilities for flood risk management as well as standards for primary flood defences.

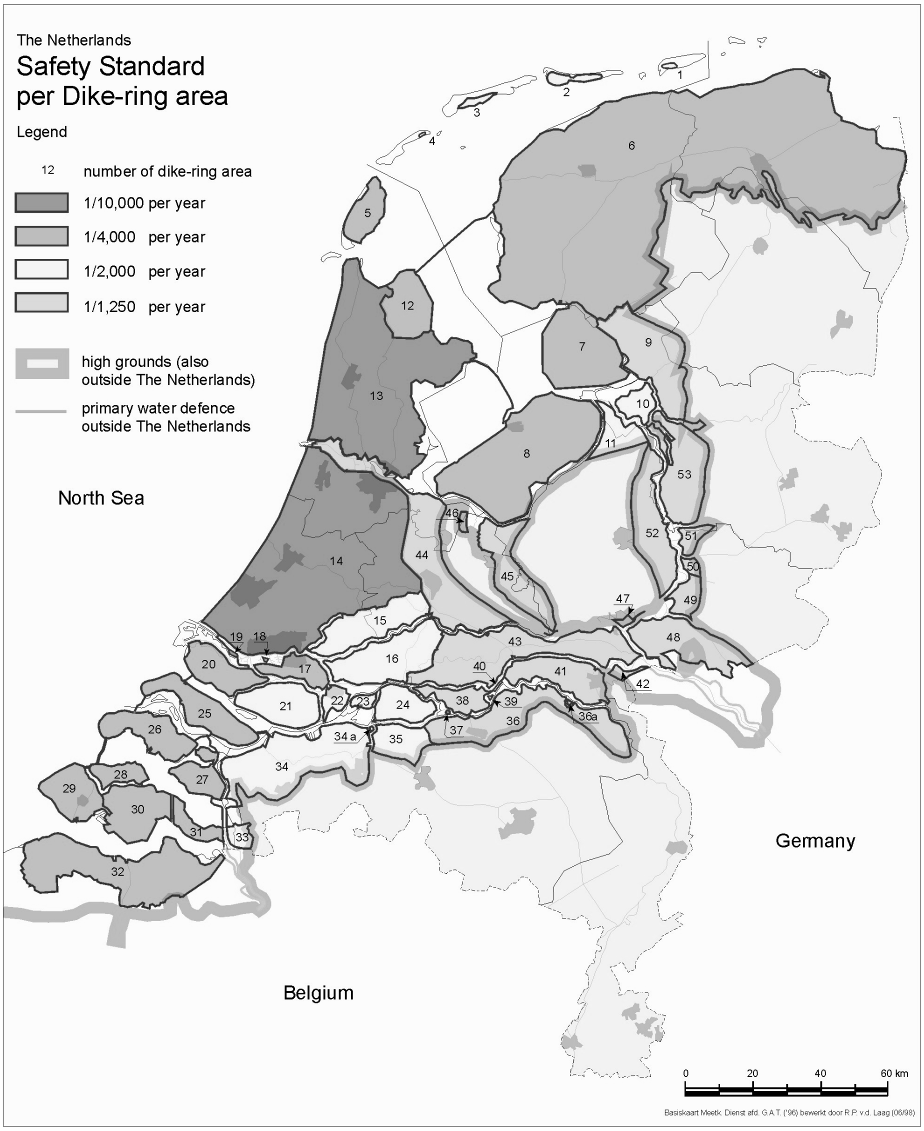

Figure 4 The standards for the Dutch primary flood defences

The safety standards shown in Figure 4 are defined as the exceedance frequencies of the water levels that the primary flood defences should be able to withstand. These exceedance frequencies should not be confused with flood probabilities. First, the safety standards are concerned with only one failure mode (overtopping), whereas there are various other failure modes that determine the probability of failure of a flood defence. Second, the standards are imposed on individual dike sections whereas the probability of flood depends on the strength of the entire dike ring. Third, the standards lay down minimum requirements.[6] Constructing a higher levee than strictly required allows the Dutch to economize on the fixed costs of future dike heightening, which is necessary to offset the effects of economic growth, subsidence, and relative sea level rise. Van Dantzig (1956), the member of the Delta Committee that introduced the risk-based design philosophy for flood defences assumed a combined rate of subsidence and relative sea level rise of 0.7m per century.[7]

While flood probabilities are often believed to rise in case of relative sea level rise, the use of probabilistic safety standards rather than fixed statutory dike heights ensures that changing conditions are met with investments in flood protection (Vrijling and Van Beurden, 1990). It could even be argued that flood probabilities should be reduced in case of relative sea level rise. After all, when potential inundation depths increase, it makes sense to better protect the Netherlands against floods. This undoubtedly comes at a cost. But the rate of relative sea level rise would have to increase drastically before flood prevention would no longer be an economically viable strategy in the Netherlands: while over 60% of the country lies below sea level, annual spending on flood defence is only 0.15% of GDP (RIVM-MNP, 2004).

1.3 Objectives and research questions

1.3.1 Objectives

The central objectives of this study were to evaluate the government's response to the challenges posed by industrial and flood risks, and to formulate proposals for improvement. The outcomes of such an endeavour depend heavily on a number of value-laden assumptions. Although the study starts off in a rather generic manner, the analyses are later narrowed down to the policy domains of industrial and flood safety. Without such focus, this dissertation would undoubtedly have become too general to yield practical results. Three important limitations of the scope of this thesis are:

1. It focuses on the Dutch industrial and flood safety policies.
2. It focuses on policy issues at strategic and tactical levels. The operational level has been left aside: methods used in e.g. quantitative risk assessments, plant inspections and audits have not been analyzed.
3. It is limited to non-malicious threats. The challenges posed by terrorism have deliberately been left aside. Static design standards and regulations can only provide limited protection against terrorist threats. Moreover, I believe that the chosen approach to policy evaluation and policy formulation (see section 1.4) is poorly suited to evaluate anti-terrorism policies. I will return to this matter in section 12.1.

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[6] The Delta Committee derived a *design* criterion that takes account of economic growth and relative sea level rise. The Flood Defense Act lays down minimum requirements that flood defences always have to meet.

[7] In the report of the Delta Committee, the effect of subsidence and relative sea level rise was assumed to be offset by periodical regeneration of the levees.

1.3.2 Research questions

Based on the objectives of this study, two groups of research questions were defined. They gave direction to this research project but they did not outline it sharply. Rather, they acted the glue that kept everything together.

1. Related to policy analysis
    a. Why regulate hazardous activities?
    b. How do current regulatory practices in the domains of industrial and flood safety influence resource allocation?
    c. What commonalities, differences and opportunities for mutual learning could be identified?
2. Related to policy formulation
    a. How to evaluate risks to the public?
    b. How could methods for risk appraisal be applied in a proportionate manner to the selected policy domains?
    c. How should arrangements for dealing with losses influence risk appraisal?

The analysis, evaluation, and formulation of public policy involve a number of subjective, and hence disputable, choices. In the natural sciences and engineering, nature always tests the validity of our claims. But in the social sciences, much depends on our interpretation of social phenomena, as well as the yardstick we use to distinguish between good and bad. There are numerous ways to analyze and formulate public policy. The choices that underlie this thesis are the subject of the following section.

1.4 Methodological choices

1.4.1 Analyzing and formulating public policy

Two archetypical frameworks for the analysis and formulation of public policy are the rational model, associated with Simon, and the incremental model, associated with Lindblom (Hague and Harrop, 2001; Parsons, 1995). The rational or blueprint model assumes an orderly policy making process in which a full assessment of a given problem is followed by a careful evaluation of alternative solutions. The incremental model on the other hand presents a rather amorphous picture of the policy making process in which various actors continuously shape public policy. The rational and incremental models are essentially the two extremes of a sliding scale.

The rational model comprises the systematic search for ways to achieve predefined goals (Table 1). While it seems impossible for people to make fully comprehensive assessments in our highly complex world, most things seem only weakly related to other things (Simon, 1983). This is recognized by the concept of bounded rationality that is related to "satisficing" rather than "optimizing" (Simon, 1978). While optimizing assumes an omniscient analyst, satisficing assumes an analyst that systematically looks for solutions. Even engineers that often consider themselves rational have to admit that their work is essentially about satisficing. Rather than coming up with *the* design they come up with *a* design that satisfies a list of requirements. Different engineers are unlikely to come up with exactly similar solutions.

Table 1
Main differences between rationalism and incrementalism

Rationalism	**Incrementalism**
Facts are "out there"	Different perspectives and interests invalidate a unitary, comprehensive assessment
Policy formulation based on a systematic assessment of an isolated part of our complex world	Policy formulation based on constant probing
Focus on efficiency and effectiveness	Focus on actors: bargaining

The incremental model refers to policy change in small steps, similar to Popper's "piecemeal social engineering" (Parsons, 1995). An incremental approach involves constant probing of problem definitions, goals and means (Hague and Harrop, 2001). It concentrates on the competition of interests and ideas rather than the search for optimal solutions (Lindblom, 1990; Lindblom and Woodhouse, 1993). The model is thereby strongly related to theories on multi-actor systems that focus on actors to explain the dynamics and outcomes of policymaking processes (e.g. Hermans, 2005; Varvasovszky and Brugha, 2000).

A distinction should be made between the use of the rational and incremental models in normative and positive analyses. Normative analyses concern value-laden questions ("ought"), while positive analyses concern description, explanation and prediction ("is"). When the rational and incremental models are used in a normative sense, they are used to *evaluate* policies or processes. Engineers for instance often criticize the policymaking process for being irrational, thereby assuming that policymaking *ought* to follow a rational model. Positive analysis concerns the extent to which a model can explain or predict observations. As analytical tools, the incremental and rational models highlight different aspects of the policymaking process. While the incremental model focuses on actors and the distribution of power, the rational model focuses on the efficiency and effectiveness of alternatives. This thesis is concerned with *normative* analysis: it is concerned with the evaluation of public policy using a specific yardstick to distinguish between inferior and superior alternatives (section 1.4.3). Criticising the conclusions and recommendations of this thesis on the grounds that the chosen yardstick assumes an orderly policy making process that is highly unrealistic would be to confuse positive and normative analysis.

1.4.2 Chosen approaches to policy analysis and formulation

The first part of this thesis concerns policy analysis. But how to analyze public policy? As Wildavsky notes "policy analysis is an applied subfield whose content cannot be determined by disciplinary boundaries but by whatever appears appropriate to the circumstances of the time and the nature of the problem" (Wildavsky, 1979: 15 in Parsons (1995): 29).

The first part of this thesis concerns policy evaluation. A choice has been made for a rational approach to policy analysis. The focus of this thesis rests on the ways in which institutions have influenced the allocation of scarcity (safety, wealth) rather than the ways in which stakeholders view and continuously shape public policy. Agency cost and an unbalanced representation of interests could make it difficult to scrutinize government action using a focus on stakeholders, many of whom are funded directly or indirectly by the government.

The second part of this thesis concerns risk evaluation. The rational model would lead us to evaluate formal methods such as cost-benefit analysis, while the incremental model would lead us to evaluate decision making processes. A choice has again been made for a predominantly rational approach. Existing practices and institutional structures have however been taken as the point of departure. This incremental starting point ensures that (elements of) this study can easily be compared with current practice, providing insights as well as alternatives whose implementation would not require too radical departures from status quo.

1.4.3 How to define a social improvement?

The evaluation of regulatory practices and the formulation of proposals for improvement presuppose that it is possible to distinguish good from bad. But how to do so? The answer to this question is by no means clear-cut. What individuals consider to be "good policy" will be strongly influenced by worldviews and social context. One only has to look at the different issue positions of political parties to realize that there is no objective standard for deciding on best or even satisfactory policies. So how to proceed? No scientist can rightfully claim to possess superior knowledge about the risks that ought to be acceptable to others (see also Fischhoff et al., 1981). Although this might sound disenchanting, it need not lead to mindless relativism. Scientists can still offer a helping hand to those faced with the thorny question "how safe is safe enough?" as long as they clearly define the moral basis of their judgments.

Could the difficulties associated with the evaluation of *outcomes* perhaps be avoided by focusing on decision making *procedures*? Unfortunately, that is not the case. In his "Social Choice and Individual Values", Arrow (1963) demonstrated that there is no way to decide whether a policy is to be preferred over another when this decision is to be based on individual preferences and some reasonable criteria concerning the decision making process.[8] In fact, the difficulty in evaluating outcomes stems from the lack of neutral or objectively superior decision making procedures. Consider for instance an attempt to resolve a dispute over the siting of a hazardous plant through a participatory decision making procedure. Who would we ask to participate? If we elect representatives, what

[8] These criteria are: (i) the existence of a social ordering (ii) a positive relation between individual and social values, (iii) the independence of irrelevant alternatives, (iv) non-dictatorship (Arrow, 1963).

rules should we use to elect them? And when decision makers cannot reach consensus, what voting rule should be used? These and other questions cannot be answered without making value judgments. Risk appraisal cannot be a neutral task.

The basic premise that underlies this thesis is that the preferences of individuals should count. The key issue about group decision making now concerns the reconciliation of different individual preferences. Under the strict Pareto criterion, a policy is considered a social improvement if it makes some better off without making anyone worse off. But policies normally involve losers as well as gainers. How to proceed in such cases? The Kaldor-Hicks compensation criterion (also named the potential Pareto criterion) says that a policy yields a social improvement (is efficient) when all could *potentially* be made better off (Hicks, 1939; Kaldor, 1939).[9] The advantage of the Kaldor-Hicks criterion over the strict Pareto criterion is that the latter would often be too restrictive to be of practical use. It is the former that is therefore often used for the evaluation of public policy. But the Kaldor-Hicks hypothetical compensation test is not without theoretical difficulties as Arrow (1963) has formally shown.

To illustrate these difficulties, consider the two pies shown in Figure 5. Which pie to prefer? The pie on the right is obviously bigger but its parts are not of equal size. The choice for the pie on the right would potentially give all of us the largest amount of pie. But when we look at the fairness of the distribution, some people might prefer the smaller pie on the left over the larger pie on the right. They might find it highly important that everyone gets the same amount of pie. Others might however point out that they enjoy eating pie more so that they should be entitled to a larger part. As Arrow cautions us: "there is no meaning to total output independent of distribution" (Arrow, 1963: 40).

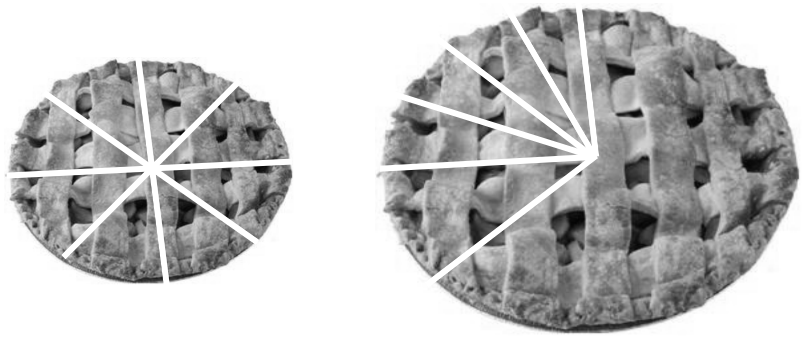

Figure 5 Total output and distribution: which pie to prefer?

As the hypothetical compensation test is central to welfare economics, it seems useful to consider societal cost-benefit studies as a starting point for a more formal discussion of why and when the hypothetical compensation test breaks down. Goods are typically

[9] The Kaldor-criterion says that the winners should be able to compensate the losers. The Hicks-criterion says that the losers should not be able to compensate the winners to stay in the present state. The Kaldor-Hicks criterion combines both criteria and is also known as the Scitovsky-criterion.

valued at their market prices in societal cost-benefit analyses. To be sure that market prices are proper measures for utility gains and losses, one has to make a normative assumption concerning the optimality of the existing distribution of wealth. The distribution of wealth determines our ability to pay and this in turn influences the outcome of the compensation test. To illustrate the matter, consider two well-known ways in which individuals can influence the organization of society: by casting dollar-votes in the marketplace, and by casting political votes in elections and referenda (Pearce and Nash, 1982). These votes differ fundamentally in two respects. First, dollar votes allow for the expression of the intensity of one's preferences while political votes follow an "all or nothing" logic. Second, the ability to cast dollar votes depends on one's income while the ability to cast political votes does not. A millionaire would have far greater ability to cast dollar votes than a person on relief. But both would have a similar say on things on the basis of their political votes. When policy appraisal is based on money votes, the distribution of wealth clearly matters.

When the existing distribution of wealth is not considered fair, the use of unadjusted prices for costs and benefits in cost-benefit studies is inappropriate (Pearce and Nash, 1982). When distributive weighting systems are not used, it is implicitly assumed that the existing distribution of wealth is a suitable point of departure. This is the assumption that is also made here. The underlying rationale is that the prevailing income distribution might be considered the result of decades of muddling through. This essentially revealed preference assumption might be disputed yet it seems the least controversial assumption to make. Note also that weighting systems are, at least in the Netherlands, rarely, if ever, used in societal cost benefit analyses.

A second issue concerns the fact that the Kaldor-Hicks criterion measures potential compensation in money terms. The maximization of money gains is equivalent to the maximization of aggregate utility under the assumption that the marginal utility of wealth is constant and the same from person to person (Arrow, 1963). Yet it seems far-reaching to assume that utilities can be compared interpersonally, and that an extra dollar in the hands of a rich man brings the same amount of pleasure as an extra dollar in the hands of a poor man.

One last issue concerns the valuation of non-market goods such as health, safety and the environment. Assumptions about the marginal utility of wealth and the use of market measures for gains and losses become meaningless when we talk about goods that have no market price. To be able to express the unpleasantness of risks in money terms, it has to be assumed that safety is commensurate with euros or dollars.

Various assumptions are needed to defend the potential compensation test as a means to appraise policy alternatives: an individual postulate, constant marginal utility of wealth that is the same from person to person, a fair initial distribution of wealth, and commensurability. While these assumptions might sound uncomforting, their practical implications might be limited when policies have little redistributive consequences, when the effects of a large number of policies cancel out, or when redistribution takes place by fiscal means (Musgrave, 1969; Scitovsky, 1951). It should also be kept in mind that *every* method for the evaluation of public policy involves a set of normative, and thereby disputable assumptions.

In defence of the chosen definition of a social improvement one could argue that the Kaldor-Hicks compensation criterion is consistent with widely held beliefs of what good policy should be like. Policymakers and politicians often refer to the total (or social) costs and benefits of policy alternatives, and societal cost-benefit analysis is frequently employed to evaluate government actions.

The basic thought underlying the chosen consequentialist ethic for the evaluation of public policy is well captured by a quote of Jeremy Bentham, one of the founding fathers of utilitarianism: "An action then may be said to be conformable to the principle of utility, or, for shortness sake, to utility, (meaning with respect to the community at large) when the tendency it has to augment the happiness of the community is greater than any it has to diminish it" (Bentham, 1780 (1970): chapter 1, 6: 12).

1.5 Some words of caution

Readers will surely have noticed that this thesis is written with a high degree of generality. Although detailed and in-depth studies are beyond doubt important to improve our knowledge of the world around us, the approach taken here is the exact opposite. By focusing on risks alone, erroneous conclusions could easily be arrived at. Attempts to link risk characteristics to forms of government intervention are for instance widespread, although these overlook the fact that risk is only part of the bigger picture. A broader analysis of public policy could reveal such errors and provide hints about ways to deal with them. The hints made throughout this thesis obviously lack detail. The primary reason for this lack of detail is the enormous effort it would take to formulate policies at an operational level. It also seems preferable to leave policy formulation and implementation up to the hundreds of professionals that staff our ministries, rather than to trust a single academic to work out public policy on his own.

Because risk regulation involves economic, political, legal, social, administrative, psychological, and technical dimensions, the study of risk and regulation is strongly multidisciplinary (see also Vlek and Keren, 1992; Vlek and Stallen, 1980). This dissertation draws upon reliability engineering, economics, and political science, and to a lesser extent on law, psychology, and public administration. Given the multidisciplinary nature of this thesis and the diversity of its intended audience, the text has deliberately been written in relatively simple language. Homer Simpson and Mr Burns, two cartoon characters, will frequently put in an appearance to clarify complex matters.[10] While some issues will undoubtedly be trivial to economists, they might not be so trivial to others. And similarly, while some issues will be trivial to engineers, they might be less obvious to economists or political scientists. I would therefore gently like to ask readers not to be too harsh on the unscientific nature of the presentation of some lines of thought and to see Homer and Mr Burns as two gentlemen that make complex theories accessible to a broader audience.

It is inevitable that the outcomes of this study will be susceptible to criticisms about the chosen yardstick to distinguish between superior and inferior policy alternatives. Although this thesis focuses on the outcomes of policies, people might also be deeply concerned about the process of getting there. Dolan et al. (2007) for instance argue that people evaluate procedures alongside consequences, implying that people have non-consequentialist reasons for their procedural preferences. Kant's first categorical

[10] I owe the idea to use these simple cartoon figures to Professor Eric Talley.

imperative stipulates "Handle nur nach derjenigen Maxime, durch die du zugleich wollen kannst, dass sie ein algemeines Gesetz werde" (Kant, 1785 (1904): 55). It seems unlikely that Kant would have agreed on a purely consequentialist ethic as a sufficient basis for the evaluation and formulation of public policy.

Although this thesis focuses the government's response to industrial and flood risks, it should be kept in mind that non-sate actors such as insurance companies, the media and advocacy groups can also exert strong influence on the behaviour of individuals or firms (Hutter, 2006). Multinationals are perhaps more worried about negative media coverage than a fine. All this does not mean that state regulations do not matter. But it should be kept in mind that the government is only part of a much broader social environment that nourishes or thwarts just or safe behaviour.

1.6 This thesis in a nutshell

This thesis is divided into four parts. Part I starts by outlining the issues pertinent to the choice for a regulatory arrangement (chapter two). Why should risks be regulated? The justifications for government intervention depend heavily on the chosen definition of a social improvement (see section 1.4). The invisible hand of the economic system would maximize the social value of production in a world without market failures (equity apart). The real world is however far from perfect. Market failures give rise to situations in which individuals that pursue their private interests no longer act in the interest of all, or even their own. The presence of market failures is therefore a necessary yet insufficient condition for government intervention under the utilitarian ethic that underlies this thesis. After a rather general discussion of the utilitarian rationales for government intervention, a more detailed discussion of the Dutch industrial and flood safety policies is presented in chapters three and four. Part I ends with a comparison of these policies and a discussion of the opportunities for mutual learning.

Part II discusses two formal methods for the evaluation of risks to the public. Chapter six deals with cost-benefit analysis, and chapter seven with societal risk criteria. As no thesis on risk decision making would seem complete without a discussion of "the" precautionary principle, chapter eight deals with this elusive principle.

While Part II deals with risk evaluation (ex ante), part III deals with potential losses (ex post). There is always a probability, however remote, that things will go horribly wrong. Should we therefore always be fully prepared? Chapter nine argues that disaster preparedness should not be evaluated in isolation and that it can be wholly justifiable to be ill-prepared for low-probability, large-scale accidents. Chapter ten then discusses flood insurance as a means to ease the economic impact of large-scale floods, and chapter eleven discusses the relations between insurance and optimal investments in system safety.

Part IV provides a discussion of the methodological choices that underlie this thesis, as well as an overview of the main conclusions and recommendations. All conclusions rest on a consequentialist ethic. Some would claim that not only *outcomes* matter but *procedures* as well. This is undoubtedly true. But to see where *any* perspective takes us (and to see where it does not, which is arguably just as important) it seems worthwhile to consistently reason from a single, well-defined point of departure. Although a consequentialist, utilitarian definition of a social improvement is obviously a rather limited basis for risk appraisal, it seems to be an important one. Trade-offs between the various things we want are part of daily life. Do we spend taxes on health care reform, education or flood protection? In a world where safety and wealth are scarce, such difficult choices are unavoidable.

PART I

An analysis of current regulatory practices

Chapter 2

Why regulate risks to the public?

Why should the government limit individual liberties through rules and regulations or try to influence individual behaviour through taxes and subsidies?

2.1 Introduction

The UK's House of Lords took the view that "there is no merit in government intervention for its own sake and that unnecessary intervention potentially imposes significant costs, which may be both economic and non-economic" (House of Lords, 2005: 7). This presumption, a presumption that also underlies this thesis, rests on the invisible hand hypothesis by Adam Smith that boils down to the phrase that: "by pursuing his own interest he frequently promotes that of the society more effectually than when he really intends to promote it" (Smith, 1776 (1976): book IV, ch.II, 9). In a world without market failures, every individual that pursues his or her private interests also acts in the interest of all. From a utilitarian point of view, a necessary (although not sufficient) condition for government action therefore lies in the presence of market failures.

Economic theory can provide interesting insights about the ways in which individuals and governments deal with risks. Economics is not just about money but about the allocation of scarcity; and just like cookies and cars, safety is a scarce good. Casual observers for instance sometimes point to the paradox that people's willingness to accept risks seems to become lower when societies become safer. The implicit causal relation seems spurious however. In a society that becomes ever wealthier, risk becomes increasingly scarce relative to wealth (ceteris paribus) which could result in a growing demand for safety. It could thus be hypothesized that it is the increasing level of wealth that drives the growing demand for safety rather than the increasing level of safety itself.

2.2 Rationales for government intervention

2.2.1 Risk as a negative externality

An externality arises when the utility or production of an economic agent A (individual or firm) depends on the activities of another agent B that does not consider the effects of these activities on A (Buchanan and Stubblebine, 1962). An externality is a special case of joint supply: it is a side-effect of production for which a market does not exist (Buchanan, 1966). As discussed by Mishan (1971: 3), "the essential feature of an external effect is that the effect produced is not a deliberate creation but an unintended or incidental by-product of an otherwise legitimate activity". When the costs of private actions fall on others, those that pursue their private interests no longer act in the interest of society as a whole: negative externalities give rise to excessive social cost.

A well known example of a negative externality is a factory that soils the neighbours' laundry (Coase, 1974). Suppose the factory bakes cookies. When the factory's smoke is an unpriced side-effect of production, the factory owner will bake too many cookies and cause too much smoke. The issue is not how to make the factory produce as little smoke as possible but how to make the factory produce the optimal amounts of smoke and cookies. After all, while we do not want our laundry soiled by smoke, we do want to eat cookies.

Externalities are often associated with the work "The economics of welfare" by Arthur Cecil Pigou (1932). Through taxes and subsidies, Pigou argued, the State should correct market failures that would otherwise be caused by externalities. A Pigovian tax is a marginal tax that fills the gap between marginal private and marginal social cost. Unfortunately, a marginal taxation scheme is not a universal panacea as devising and levying a marginal tax is often complex and costly (Turvey, 1963). The position that government intervention would always be needed for maximizing the social value of production has been challenged, most notably by Nobel prize laureate Ronald Coase. He pointed to the costs of government intervention and raised awareness for the reciprocity of externalities. To reduce the soiling of our laundry, we could make the factory owner bake less cookies but we could also dry our laundry elsewhere. When it would be most cost-effective to move our laundry indoors, imposing a marginal tax on the factory owner would not be an efficient strategy.

As shown by Coase (1960), a private bargaining process maximizes the value of production when property rights are assigned and transaction costs are absent. Transaction costs can however be found throughout economic life; they are essentially the "costs of running the economic system" (Arrow, 1969: 60). Organizing transactions can sometimes be so costly that private bargains do not come about (Whitcomb, 1972). The government could then be called upon to deal with the externality. The government can set rules and use its authority to enforce them. Put differently, the government may act as a "super-firm, since it is able to influence the use of factors of production by administrative decision" (Coase, 1960: 17). A few examples of government intervention are the prescription of methods of production, the adoption of minimum safety standards, the introduction of mandatory insurance, and the enforcement of a ban on certain activities.

It is often forgotten that government intervention is not without cost itself. The administrative cost of decision making, implementing policies and enforcing rules are often considerable. Moreover, regulations inevitably produce inefficiencies of their own as "general regulations which must apply to a wide variety of cases will be enforced in some cases in which they are clearly inappropriate" (Coase, 1960: 18). When the costs of government action exceed potential gains, the only optimal decision would be to not take action at all (equity apart).

There are three main options to remedy the presence of negative externalities: (i) regulate the hazardous activity, (ii) bias individual decisions through e.g. taxes and subsidies, or (iii) establish private ownership and leave it up to the market. Table 2 presents three examples of negative externalities, as well as the government's response to each of them.

Table 2
Examples of attempts to remedy (consequences of) negative externalities

Fine dust and nitrogen dioxide	Fine dust (PM_{10}) and nitrogen dioxide (NO_2) are pollutants caused by (amongst other) the burning of fossil fuels. The EC recently established criteria for air quality. These criteria cannot always be met in the densely populated Netherlands. The cabinet proposed various measures to avoid the cancellation of construction projects such as ""salderen": when a project causes local deterioration of air quality it might still be allowed if its net effect on air quality is positive. An example would be the widening of a ring road that improves the air quality within a city but that aggravates the situation for those living along that road. Note that "salderen" is about total output rather than distribution.
The production, storage and transport of hazardous materials	The production, storage and transport of hazardous materials give rise to third party risks, i.e. risks to those that are not actively involved in these activities. These risks are the subject of external safety regulations. The Dutch external safety regulations will be discussed in greater detail in the next chapter.

2.2.2 Risk reduction as the provision of a public good

A pure public good is characterized by non-rivalry and non-excludability. Non-rivalry means that consumption by one individual does not reduce another individual's ability to consume. Non-excludability means that it is impossible to exclude people from consumption. Public goods are different from private goods. An apple for instance can be sold to only a single individual and it can be enjoyed only once. This is clearly not the case when it comes to a pure public good such as national defence. Note that a public good is a special case of a (positive) externality but that not all (positive) externalities are public goods. The reason for treating public goods here is that measures to mitigate risks are sometimes public goods. National defence has already been mentioned: for many centuries (and arguably even today), a military was (is) needed to reduce the risk of pillage and plunder. Other examples of risk-reducing public goods are lighthouses and flood defences.

The funding of public goods is typically troublesome under laissez faire because it is difficult to collect payments from the beneficiaries of goods that are characterized by non-rivalry and non-excludability. People could get more than they pay for if they were to pretend not to value the goods they consume as much as they truly do (Samuelson, 1954). But if everyone were to act so, aggregate willingness to pay would become severely limited. Government intervention could resolve the underlying co-ordination problem. Interestingly, Adam Smith already considered the funding of the military and the construction of public works government tasks: "According to the system of natural liberty, the sovereign has only three duties to attend to; three duties of great importance, indeed: first, the duty of protecting the society from the violence and invasion of other independent societies; secondly, the duty of protecting, as far as possible, every member of society from the injustice or oppression of every other member of it, or the duty of establishing an exact administration of justice; and thirdly, the duty of erecting and maintaining certain public works and certain public institutions, which it can never be for the interest of any individual, or small number of individuals, to erect and maintain; because the profit could never repay the expense to any individual or small number of individuals, though it may frequently do much more than repay it to a great society" (Smith, 1776 (1976): book IV, ch.IX, 51).

Saying that the funding of public goods is unlikely to be optimal under laissez faire is not similar to saying that public goods cannot be privately provided. An illustrative example concerns Coase's review of the operation of lighthouses in England and Wales (Coase, 1974). Lighthouses are widely perceived to be pure public goods: the number of fishermen out on the ocean does not influence the degree to which a lighthouse can be seen (non-rivalry) and it seems practically impossible to exclude fishermen from seeing a lighthouse (non-excludability). Yet Coase showed that the English and Welsh lighthouses had for long been privately operated. This should however not be interpreted as a universal claim that all public goods can also be provided by private enterprise or as evidence that lighthouses are in fact not public goods. Rather, the lighthouse example should be considered a special case in which the government had privatized the right to collect duties (these are essentially taxes) on another service (unloading ships) to fund the operation of lighthouses (Samuelson and Nordhaus, 2005). The problem associated with the funding of a public good was thus effectively solved through taxation (coercion).

A government has three main options when attempting to remedy failures of the free market to produce public goods (i) provide the public good itself, (ii) stimulate the provision of a public good by private enterprises through subsidies, regulations, or by granting private firms the right to collect duties, (iii) do nothing. Table 3 presents two examples of public goods.

Table 3
Examples of the provision of public goods

Flood defence	The benefits of flood defence are indivisibly spread amongst the inhabitants of a flood prone area. The provision of flood safety will be discussed in greater detail in chapter 4.
Aids to navigation	Buoys help sailors navigate. In the Netherlands, aids to navigation are provided by the government.

2.2.3 Risk and imperfect information

Lack of information could prevent people from doing what would serve their interests best. But acting on the basis of imperfect information need not be irrational. Gathering and processing information takes considerable effort. A rational utility maximizer would try to economize on this effort (see also Downs, 1957). Scientists that devote their lives to the study of a single phenomenon will surely agree that comprehension comes at a cost. But when acting on the basis of imperfect information need not be irrational, why bother about it?

Sometimes, it can be unduly troublesome or costly to obtain information because barriers are deliberately put up to prevent people from acquiring information. Government intervention might be needed to remove such barriers.[11] People might be unwilling to disclose information because of the advantages that secrecy brings, even when this secrecy brings considerable harm to others. Another case in which government action might be called for is when widely held misperceptions or lack of knowledge cause unnecessary individual losses or considerable social cost. Informing the public about ways to prevent diseases such as AIDS and malaria can reduce unnecessary suffering.

When attempting to reduce excessive social costs arising from information imperfections, the government could (i) inform the public, (ii) regulate the provision of information, (iii) regulate the activity, or (iv) do nothing. Table 4 presents two examples of imperfect information.

[11] Note that the government also protects information monopolies to stimulate innovation. Patents protect firms for a limited period of time from copy-cats to allow them to benefit from their investments in research and development. This has little to do with imperfect information but with positive externalities.

Table 4
Examples of attempts to remedy (the consequences of) imperfect information

Smoking	The government tries to educate the public about the health risks of smoking through campaigns and warnings on cigarette packages. Besides attempts to remedy imperfect information, one might also consider this an attempt to discourage the consumption of a demerit good, as will be discussed in section 2.1.5.
Safe sex/AIDS	Educating youngsters about safe sex is part of most secondary school curricula in the Netherlands. The thought behind these attempts to educate the public is that people are able to make sensible decisions, if properly informed (or that alternative government actions are less attractive).

2.2.4 Risk and demerit goods

Unlike merit goods, whose consumption is considered worthwhile, demerit goods are goods that are considered harmful (Samuelson and Nordhaus, 2005). Examples of demerit goods include tobacco, alcohol and heroin. The basic idea behind government intervention is here that not all individuals are capable of making decisions that serve their interests best, even if they would be given perfect information. The government might step in to discourage consumption through (i) regulations (e.g. age limits for the purchase of alcohol or a ban on heroin), (ii) taxes (e.g. taxes on tobacco), (iii) assistance in reducing consumption (e.g. free drug rehabilitation), or (iv) campaigns (e.g. ads to discourage drug use).

Unlike imperfect information, demerit goods do not give rise to market failures. Government intervention is motivated primarily by the moral questions these goods raise. One could inform people on the detrimental and addictive effects of heroine but still not trust people to make choices that serve their interests best. Addiction to demerit goods often causes criminal behaviour which gives rise to considerable social cost. But this does not have to be so. Millionaires would probably have little difficulty to fund their addictions. Yet few would argue that heroin use would be less of an issue when people would be wealthy enough to support their addictions. The main motivation for government action here seems to concern our moral responsibility to prevent people from harming themselves: we simply cannot believe that people would freely, willingly destroy their minds and physiques.(Adler and Posner, 1999)

It is perhaps insightful to relate the discussion of demerit goods to the definition of a social improvement that underlies this thesis (see section 1.4.3). The assumption that individual preferences should count would lead us to the conclusion that people should be allowed to decide for themselves whether they smoke or not, as long as they are properly informed about the risks and carry the associated costs for e.g. medical treatment themselves (the issue of harm from second-hand smoke apart). For why should we deny people the pleasure of smoking or even heroine use?[12] The important lesson from all this is that there are different ways to define social improvements and that these different definitions can lead to very different judgments. Under the definition of a social improvement that underlies this thesis, only market failures would classify as legitimate reasons for government intervention. As demerit goods do not give rise to market failures, policies to reduce e.g. the consumption of cigarettes would not classify as social improvements here.[13] In real life, people typically use different yardsticks to distinguish between good and bad. Although the chosen ethic on which this thesis rests might be considered too restrictive by some, it seems useful to see where it takes us. But even more interesting, perhaps, is to see where it does not.

2.2.5 Voluntariness, control and direct benefits

Sections 2.2.1 to 2.2.4 discussed rationales for government intervention from the viewpoint of welfare economics (taking into account the assumptions discussed in section 1.4). These rationales are intricately linked to several variables that are often associated with calls for government intervention: a low degree of voluntariness, a low degree of direct benefits, and a low degree of control. But it could be argued that these are symptoms rather than diseases. All *negative* externalities are by their nature related to low voluntariness, low direct control (at least over the source) and low direct benefits. The same holds for *positive* externalities, apart from their direct benefits. Based on the low degrees of voluntariness and control over exposures to industrial and flood risks, these risks are often perceived to be rather similar while in fact they are not. After all, industrial, third party risk is a negative externality while flood risk is not. This difference has (or should have) important implications for our understanding of government actions in both policy domains.

2.3 Concluding remarks

1. The question whether the government should step in and limit individual freedoms or bias individual decisions through taxes and subsidies is of paramount importance. The utilitarian perspective adopted throughout this thesis would lead to the conclusion that there is no need for risk regulation unless there are significant market failures. After all, in a world without market failures, individuals that pursue their private interests would also act in the interest of all: unregulated individual behaviour would produce the largest economic pie (see also section 1.4.3).

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[12] Adler and Posner (1999) take a different view. They characterize such pleasures as objectively bad, and argue that they should be ignored in welfare economic appraisals.

[13] Unless of course, some costs, such as the cost of medical treatment, fall on others. In that case, there would be negative externalities.

2. Externalities (third party risks), problems surrounding the funding of public goods (flood defences), and imperfect information can give rise to excessive (suboptimal) risks. The government can influence the allocation of resources through the delimitation of rights, regulations, taxes, subsidies, and the provision of services.

3. Although the presence of market failures is a necessary condition for government intervention, it is by no means a sufficient one. The benefit of the intervention should outweigh its cost. Non-intervention is an option that should not be too easily be dismissed.

Chapter 3

The Dutch industrial safety policy

Through liability rules and regulations, the government has attempted to internalize and optimize third party industrial risks. A simple example will illustrate the interrelations between key variables. The chapter then proceeds by discussing current regulatory practices in somewhat greater detail.

3.1 Introduction: risk as a negative externality

3.1.1 The case without transaction cost

Let us consider the town of Springfield where Mr Burns owns and operates a power plant. Mr Burns sells his electricity to (amongst other) barkeeper Moe. Homer Simpson is a regular customer of Moe's tavern where he enjoys drinking beer (Figure 6). All seems fine in Springfield until we notice that the power plant not only produces electricity but possibly also an explosion. Homer Simpson lives near Mr Burns' power plant and his house will be destroyed in the unfortunate event of an explosion. Homer could reduce this risk by converting his house into a bunker. And Mr Burns could reduce the risk to Homer's property by improving the safety of his plant. Let us assume that neither Homer nor Mr Burns could be made better off by resettling elsewhere and that there are no information asymmetries between the two men.[14]

First, consider the case in which Mr Burns has to compensate Homer for putting him at risk. As the amount of compensation paid depends on the level of third party risk, Mr Burns will reduce third party risk to such a level that he minimizes his overall expenditures. Assume that Homer initially values the risk of his house being blown up at \$100 (one could think of this as the cost of insurance coverage), and that this figure could be reduced to \$40 by converting the house into a bunker (costing \$5), or by installing a plant safety device (costing \$25). As Mr Burns tries to minimize his expenditures, he will try to persuade Homer to build a bunker rather than invest in a relatively costly plant safety device. Mr Burns could compensate Homer for having him

[14] For reasons of simplicity, it is assumed that all losses are commensurate with money, and that all optimum conditions are met in all sectors of the economy apart from the one under consideration.

convert his house into a bunker. Homer would profit from accepting any offer above $5, and Mr Burns would profit from any offer accepted by Homer below $25. Clearly, there is room for a mutually beneficial bargain. The end result of bargaining would be that Homer builds a bunker and that Mr Burns and Homer are left with a total gain of $55 (100-40-5=55 or 35+20=55). Mr Burns will gain $(55-X) and Homer $X ($0 \leq X \leq 20$).

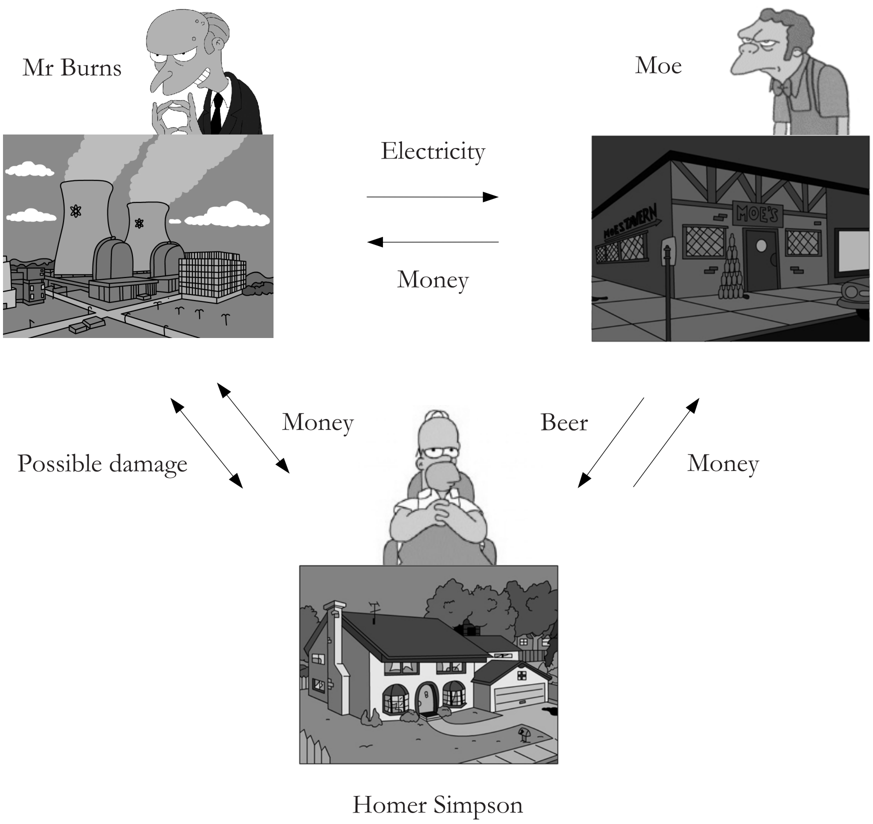

Figure 6 The transactions between Mr Burns, Moe and Homer

Now let us assume that Homer has to bear the financial burden.[15] He will convert his house into a bunker, which leaves him with a net gain of $55 (100-40-5=55). Hence, under both entitlements, Homer converts his house into a bunker. When transactions are costless, our rational utility maximizers spend every dollar where it is most cost-effective. We only have to decide whose problem the risk to Homer's property initially is. Is it Homer's initial right to live in a world free from third party risk (then Mr Burns has to compensate Homer for risk-bearing)? Or is it Mr Burns' initial right to operate a power

[15] As all gains can be redistributed through the tax mechanism, Mr Burns and Homer could both benefit from Homer's efforts to build a bunker.

plant (then Homer has to carry the cost of risk-bearing)? In a world without transaction costs and information asymmetries, the only thing the government would have to do is decide on the entitlement. Private bargaining would then do the trick in allocating resources efficiently.

So far, it has been assumed that Mr Burns, a price taker, is unable to pass on risk-related costs to the buyers of electricity. Now let us relax this assumption, and assume that Mr Burns is able to do so. Let us further assume that Moe is able to pass these costs on to the buyers of his beers (competition in the electricity and beer markets is no longer perfect). Although Mr Burns will pass on all risk-related costs, he has not lost the incentive to convert Homer's house into a bunker. After all, he could maintain his electricity price after having paid Homer to build a bunker. Again, the most cost-effective measures would be taken in a world without transaction costs and information asymmetries.

3.1.2 The case with transaction cost

The costs of organizing transactions can be expected to be considerable when large numbers of producers and/or consumers are involved (Baumol and Oates, 1988). And when bargaining private bargains cannot be reached, an external diseconomy arises (the market for the trading of third party risk is no longer there). When Homer and Mr Burns cannot reach a bargaining solution, their selfish behaviour may no longer lead to an efficient allocation of resources. Suppose the entitlement is such that Mr Burns has to compensate Homer for putting him at risk. When bargains cannot be reached, there is no way Mr Burns can compensate Homer, and Homer will not accept exposure. Mr Burns will now have to invest heavily in the safety of his plant (or close it down) to make sure Homer is perfectly safe.

Had the entitlement been such that Mr Burns was allowed to generate third party risk, Mr Burns would not be concerned about Homer's exposure. As Homer cannot offer compensation to make Mr Burns behave differently, he can only reduce the risk to his property by converting it into a bunker. In our fictitious example, this would not give rise to excessive social cost. After all, it was assumed that Homer, not Mr Burns, could mitigate third party risks most cost-effectively. If, however, Mr Burns should also invest in plant safety to arrive at the optimal solution, the absence of market transactions would give rise to excessive social cost.

3.1.3 Government intervention

When private bargains are unlikely to come about, the government might step in and use its authority to influence the allocation of resources through rules, taxes and subsidies. The government could, amongst other, impose a levy on hazardous materials, prescribe safety measures, introduce (strict) liability rules, mandate insurance coverage, or define a safety zone. From an efficiency standpoint, government intervention should ideally bring about an allocation of resources that would arise in a world without market failures. After all, in such a world, every dollar would be spent where it would be most cost-effective. Neither too much nor too little would be spent on risk reduction.

Deciding on appropriate interventions is by no means a simple task. While the polluter pays principle is frequently endorsed as a guideline for regulatory action, previous sections have already shown that this principle might lead to cost-ineffective measures being taken. When Mr Burns and Homer cannot reach a bargaining solution and Homer could take the most cost-effective measures, demanding Mr Burns to take action would not be optimal. An allocation of the financial burden that violates the polluter pays principle is not purely hypothetical. In 2005 for instance, two municipalities and the province of Gelderland subsidized a polluting factory, "De Nijmeegsche IJzergietery", to construct a tall chimney and to install dust filters. And in 2006, the structural transport of chlorine by railroad came to an end after the government had paid Akzo Nobel 65 million euro for relocating its chlorine production activities. Because of the reciprocity of third party risks, there is no simple, universal answer to the question who should pay for risk reduction. Principles that make such claims should thus be avoided.

In the absence of a private bargaining solution, a marginal or Pigovian tax could close the gap between the marginal private and social cost of the externality generating activity. This, then, would lead to an efficient allocation of resources. Those suffering from the externality should however not be compensated for their losses (Baumol and Oates, 1988). After all, full compensation can give rise to moral hazard on the part of those that suffer from the external diseconomy (Olson Jr. and Zeckhauser, 1970). Homer would for instance never consider it worthwhile to convert his house into a bunker (even though we might want him to) if he lost the incentive to do so. If, however, Homer would have to pay for damages himself, while Mr Burns was charged a marginal tax equal to marginal social damage, they would always allocate resources efficiently. To address concerns over equity, the profits made by Mr Burns could be redistributed through the tax mechanism.

Unfortunately, a tax regime is not a universal panacea as it can be difficult and costly to design and levy optimal marginal taxes. In practice, a patchwork of policy instruments might do a better job at optimizing third party risks. These different policy instruments should not be designed in isolation. Consider for instance the case in which the level of third party risk is proportional to the output of Mr Burns' plant. Assume that Mr Burns is not liable for third party damages but has to pay a marginal tax equal to marginal social damage. If the government were to change liability rules so that Mr Burns would become liable for damages, the government should also lower the marginal tax. Without an adjustment of the marginal tax, Mr Burns would reduce his electricity production beyond the optimal level.

It perhaps sounds odd that a risk can be "too low". But industrial, third party risks are the by-products of otherwise socially advantageous activities, in this case electricity production and housing; we simply cannot have the one without the other. Electricity, housing and safety are all scarce and valuable goods. Risk regulation is therefore essentially a balancing act. Because risk is the by-product of electricity production, absolute safety would require the shut-down of Mr Burns' power plant. If this were to hold for all power plants, Moe would not be able to buy the electricity to light his tavern, and Homer would have to drink lukewarm beer in the dark. It seems unlikely that this situation would satisfy Homer, even though he would be as safe as ever.

3.1.4 The role of insurance markets

The examples constantly spoke of risks "worth" e.g. \$100 or \$40. These values could be thought of as insurance premiums. Insurance purchases replace uncertain expenditures with certain ones: the probability of a financial setback is exchanged for a fixed annual sum, the insurance premium. The cost of risk-bearing will typically be lower for insurers than for individuals or firms because insurers can construct balanced portfolios of large numbers of uncorrelated risks. A person will purchase insurance coverage when the certainty thus bought outweighs the cost of coverage (see chapter eleven). An insurance purchase is essentially a means to reduce the cost of risk-bearing, just like the installation of safety devices or the conversion of houses into bunkers.

There are important differences between risk mitigation (e.g. converting houses into bunkers) and risk transfer (e.g. purchasing insurance coverage). Insurance reduces the variability of a policyholder's expenditures but the cost of insurance coverage typically exceeds expected loss. Physical measures on the other hand generally reduce the variability of expenditures, but possibly also their expected value. Whether the expected value of expenditures goes up or down depends ultimately on the (often relatively certain) cost of risk reduction.

While insurance markets allow individuals and firms to transfer risks so as to minimize the cost of risk bearing, they do not affect the basic results of the preceding sections (provided insurance does not give rise to moral hazard). With and without insurance, Homer and Mr Burns can reduce the cost of risk bearing by investing in risk reduction. Risks will however be considered more unpleasant when they are not insured than when they are. And this, in turn, implies that Homer and Mr Burns' would invest more in risk reduction if insurance were unavailable.

3.1.5 Some qualifications

One might argue that the results of the preceding sections rest on some rather unrealistic assumptions about human behaviour. This is entirely true: it has been assumed that Homer and Mr Burns are omniscient utility maximizers that are only interested in selfish material gain. And in pursuing their private interests, they were not at all led by considerations about "just" of "fair" behaviour.

Although the behavioural assumptions that were made hardly seem realistic, assumptions are inevitable if we want to reduce the complexities of real-life phenomena to manageable proportions. While it would obviously be incorrect to assume that individuals are solely led by selfish material gain, it would seem even less realistic to assume that individuals are not at all led by such selfish motives. As Buchanan and Tullock (1962: 28) posed: "the only test of a model lies in its ability to assist in understanding real phenomena".

A considerable body of scholarly work discusses the possibility of resolving public opposition to the siting of locally undesirable land uses (LULUs) through compensation. Facilities such as prisons, power plants and dump sites produce benefits that are dispersed throughout society, while the costs are concentrated on relatively small communities. Every community is therefore likely to oppose such a facility, even though it would benefit society at large. To resolve siting issue, various scholars have proposed the compensation of host communities (e.g. Kunreuther and Kleindorfer, 1986; Ohare, 1977). Empirical studies from the US demonstrate that compensation, be it monetary or non-monetary, can reduce public opposition to the siting of locally unwanted facilities, although results are mixed; for facilities that raise strong moral concerns such as nuclear waste repositories compensation can even intensify opposition as it could be perceived as a bribe and crowds out public spirit (Kunreuther and Easterling, 1996). In the long run however, people often seem to change their moral standards to match their economic interests when it comes to compensation for locally undesirable land uses (Frey et al., 1996).

All in all, the rational actor model seems valuable for structuring the problem at hand and for illuminating basic trade-offs, even though it rests on rather restrictive assumptions and can at best provide partial explanations for human behaviour. A first important result is that a risk is not automatically something that needs to be remedied through government intervention. The second important result is that liability rules, taxes, subsidies and regulations all influence the behaviour of market participants, and that their consequences sometimes overlap. Given these interactions, it would be incorrect to evaluate the stringency of e.g. zoning or liability rules in isolation.

3.2 Optimizing industrial safety: liability and regulation

As discussed in previous sections, there would be little need for risk regulation if the market were to operate perfectly (equity apart). But the many limitations of arriving at private bargaining solutions led Wellisz (1964: 354) to conclude that "The discussion of conditions under which the modern-old solution is valid leads to the conclusion that far from being a universal panacea, the private bargaining solution to external diseconomies applies only to exceptional cases". When individuals have to compensate plant owners for mitigating third party risks, every exposed individual would benefit from understating his or her willingness to pay. And when the initial entitlement is such that plant owners have to compensate exposed individuals for putting them at risk, it would pay every individual to overstate his or her true grievances. Also, because low-probability risk is largely unobservable, it might be troublesome to determine who is at risk and to what extent. And to make matters even more complicated, people could value the safety of others.

As private bargaining solutions seem unlikely, government intervention is needed to optimize industrial, third party risks. But the costs of government intervention could be considerable and exceed the gains thus obtained. If that were to be the case, the preferable strategy from an efficiency standpoint would be not to intervene. Yet all industrialised countries have implemented major hazards policies, suggesting that non-intervention is unlikely to be optimal. The option of non-intervention will therefore be left aside.

Government intervention currently consists of plant safety requirements and zoning regulations in combination with liability rules. A convincing argument for the combination of ex ante regulation and ex post liability as an optimal scheme for the control of large-scale industrial risks has been put forward by Arcuri (2005). Regulation alone would be inflexible and therefore be unable to effectively cope with technological innovation and the out-of-the-ordinary. Enforcement of rules might be difficult and costly, and plant owners are likely to be reluctant to disclose sensitive information to a regulator. These issues can be remedied through liability rules. But liability alone also has its weaknesses. Insolvency and the possibility that plant owners escape liability could lead to underdeterrence (Van Dunné, 2002; Arcuri, 2005). By combining liability and regulation, the strengths of the one can compensate for the weaknesses of the other.

The Borghouts committee that advised the Dutch cabinet on matters related to the compensation of victims of disasters, recommended full mandatory insurance for companies that fall under the BRZO (Disasters and Calamities Compensation

Committee, 2004). Although the remuneration of victims was the committee's primary concern, the measure would also have consequences for deterrence as it would effectively redistribute part of the financial burden for accidents.

Two additional remarks concerning liability are in place. First, the possibility of a plant owner escaping liability should not always be considered disadvantageous (see also section 3.1). If, for instance, victims can more cost-effectively reduce risks than plant owners, they should be stimulated to do so. An optimal Pigovian arrangement for the control of third party risks calls for a marginal tax on the producer of the external diseconomy and zero compensation or taxation on those that are adversely affected (Baumol and Oates, 1988). If all damages would always be fully compensated and there were no information asymmetries, victims would lose the incentive to take cost-effective measures to avoid losses (including taking up residence elsewhere).[16] Although it is admittedly unrealistic that victims will always be fully compensated or that they are fully informed, the reciprocity of third party risks should not be ignored.

Second, large-scale accidents have the potential to cause widespread public anxiety. An accident at an LPG fuelling plant is likely to cause concerns about public safety throughout the Netherlands. These concerns represent a welfare loss that should be part of the equation. Narrowing the analysis of liability rules and regulations down to just Mr Burns and Homer Simpson (or in general: tortfeasors and plaintiffs) is likely to yield results that Homer and Mr Burns would consider optimal, but that would be considered suboptimal by the wider population (see also section 3.3.1). Besides stringent rules, there are various other ways to increase deterrence, such as raising compensation payments awarded in court. After the ExxonValdez oil spill, a system of triple damages (tripling compensation payments for damages) was introduced in the US to increase deterrence (Van Dunné, 2002).

3.3 Individual and societal risk criteria

3.3.1 The rationale behind societal risk criteria

Without societal risk criteria, it seems likely that the probabilities of large-scale accidents would become too high from a societal perspective. To see why, consider again Mr Burns and Homer Simpson (Figure 7). Assume they would be able to reach a private bargaining solution. While the outcome of private bargaining might satisfy Homer and Mr Burns, it might not satisfy the people of Springfield that are deeply concerned about the safety of Homer Simpson. When Springfield's residents also want Homer and Mr Burns to reduce risks, aggregate willingness to pay for risk reduction exceeds that of just Homer or Mr Burns. To stimulate Mr Burns and Homer to reduce risks to lower levels than they would themselves, the people of Springfield could offer Mr Burns and Homer subsidies. And, provided there is a government, they could vote for, amongst other, triple damages and zoning regulations.

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[16] This also presupposes that the potential victims are aware of their exposures. Lack of knowledge could for instance be addressed by rules and procedures to inform the public.

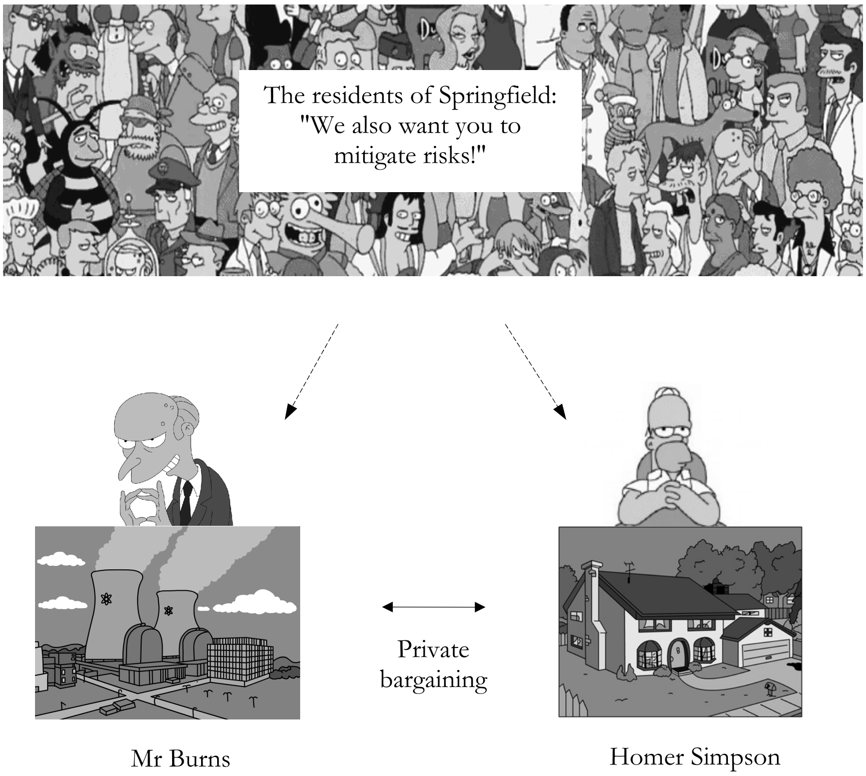

Figure 7 Homer, Mr Burns and the residents of Springfield

3.3.2 The rationale behind individual risk criteria

Under the utilitarian ethic that underlies this thesis, decisions are characterized as social improvements when they raise aggregate utility. Could risk criteria that protect an individual from the wishes of the majority fit such an ethic? The crucial assumption underlying the following exposition is that the market does not function properly so that private bargains cannot be reached. When disproportional exposures would be valued grossly disproportionately by individuals, the use of individual risk criteria could then be wholly conformable to the principle of greatest aggregate utility. Denote the intensity of an individual's exposure (such as the probability of death) by g_i (i=1..n). The population's aggregate (dis)utility would equal $\sum U_i(g_i)$, where U_i denotes an individual's (dis)utility function[17]

If individuals were to value disproportional exposures strongly disproportionately, aggregate utility would be dominated by the pains caused by these disproportional exposures. Utility maximization would then call for a means to prevent such disproportionalities. Individual risk criteria could be practical instruments for that

[17] This summation presupposes cardinal utility and interpersonal comparability of utility (see also chapter 11).

purpose. Supplementing societal risk criteria with individual risk criteria could thus be wholly conformable to Bentham's greatest happiness principle.

But would individuals be exposed to probabilities of harm that they themselves (Homer) or others (the population of Springfield) would find grossly unpleasant without individual risk criteria? The answer to this question is subject to debate. Some argue that the probability that a bystander is killed by an accident involving hazardous substances will be extremely low anyway because of, amongst other, industry and occupational standards that limit accident probabilities. According to this view, there would be little reason to assume that aggregate utility would be dominated by concerns over *individual* exposures without individual risk limits. The currently used individual risk criteria would then be little use, insofar as legally binding individual criteria (that can also be plotted on a map) are not practical means to limit *societal* risks.[18] Others however oppose this view, arguing that individual risks would strongly increase without individual risk limits.

3.3.3 Evaluating the stringency of risk criteria

Evaluating the stringency of risk criteria is troublesome as it would require us to have some measuring rod for the social costs and gains of less or more stringent risk criteria. With such a device, the optimal stringency of risk criteria could be found by equating marginal costs to marginal gains (equity apart). But without it, it seems an impossible task to evaluate the stringency of current risk criteria. A way to gain insight into the (un)reasonableness of current criteria would be to consider the way in which they were brought into being. Although this procedural approach obviously cannot provide exact answers, it does provide useful insights.

The stringency of current risk criteria in the field of external safety was originally based on an evaluation of the costs (falling primarily upon the State) and the benefits of risk reduction (Roodbol, 1998; VROM, 2002). Unfortunately, it would be too soon to conclude from this balancing exercise that the externality has been optimized. After all, it would be incorrect to think of the government as a unitary actor, acting as a benevolescent despot on behalf of society as a whole.

Political decision making on a less than unanimity basis creates external costs of its own when decisions involve losers (Buchanan and Tullock, 1962). These external costs remain limited when political decisions are strongly driven by consensus. The Dutch political system is typically categorized as a consensus democracy: consensus seeking in politics (coalition government) and interest group corporatism are amongst the cornerstones of the Dutch political system (Andeweg and Irwin, 1993; Lijphart, 1999).

Apart from the political process, it is important to consider the bureaucracies that play an important role in devising regulations and implementing policies. On the basis of Niskanen's public choice theory of the behaviour of bureaus (Niskanen, 1968; Niskanen, 1974), one would expect bureaucracies that operate under a budget mechanism to produce inefficient outputs. Niskanen's theory is based on the assumptions that bureaucracies attempt to maximize their budgets and that they have monopoly control over the information needed by sponsors. This monopoly control allows them to secure excessive funding. The theory would predict a disproportional emphasis on safety (overspending on public safety), i.e. relatively stringent risk criteria.

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[18] Under this interpretation, *individual* risk criteria supplement *societal* risk criteria (that are not legally binding and not easily plotted on a map) to prevent excessive *societal* risks.

The empirical evidence for Niskanen's theory is however poor (Parsons, 1995; Dunleavy, 1986) and an alternative theory has been formulated by Dunleavy. Dunleavy's bureau-shaping model is based on the premise that senior administrators pursue private interests that need not correspond to the maximization of a bureau's budget (Dunleavy, 1986). In refining Niskanen's theory, Dunleavy's bureau shaping model discerns between different types of budgets (Dunleavy, 1986). The core budget is the budget that is related to the control-activities of an agency. Programme budgets are allocated by agencies but do not influence the funds that are at the agency's disposal. Dunleavy argues that core budgets strongly determine the welfare of policy-level administrators so that senior administrators attempt to maximize these. This however does not hold for programme budgets, and this is where Niskanen and Dunleavy part. The budget that was available for the removal of bottlenecks caused by the introduction of zoning regulations (risk criteria) could be characterized as a programme budget. Based on Dunleavy's bureau shaping model, it seems unlikely that the workings of the bureaucracy have given rise to excessive public investments in external safety, and hence to excessively stringent risk criteria.

This circumstantial evidence makes it reasonable to assume that the Dutch risk criteria have at least *contributed* to an efficient allocation of resources: the stringency of the risk criteria was based on an out-of-the-ordinary budget for risk reduction, decided on in political system that could be characterized as a consensus democracy.

The word "contributed" is emphasized because inefficiencies inevitably result as "general regulations which must apply to a wide variety of cases will be enforced in some cases in which they are clearly inappropriate" (Coase, 1960: 18). The Dutch societal risk criterion was originally developed for LPG fuelling stations, which form a relatively homogeneous group of hazardous establishments. The criterion was then generalized to all hazardous establishments including refineries and even airports (although the latter attempt failed). The same FN-criterion thus applies to establishments of different character and size. Similarly, the FN-criterion for the transport of hazardous materials is the same regardless of the kilometre under consideration. The uniformity of societal risk criteria could perhaps be explained by the political process. As posed by a former senior administrator, politicians considered it politically unfeasible to adopt less stringent criteria than those that had already been established for LPG-fuelling stations.

Because local circumstances vary considerably, so do the marginal costs of risk reduction. An FN-criterion that is reasonable for some establishment or transport kilometre need not be reasonable for another as well.[19] An equity consideration ("the same societal risk criterion should apply to all establishments and kilometres") often seems to interfere with the efficiency argument that underlies the use of societal risk criteria.[20]

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[19] Stand-still (the principle that societal risks should not get worse unless properly motivated) often effectively provides a more stringent benchmark for evaluating FN-curves.

[20] One might argue that uniformity of regulations is desirable because non-uniform criteria could give rise to considerable transaction cost. This, however, need not be the case.

3.4 The ALARA-principle

The ALARA-principle (As Low As Reasonably Achievable) is a guiding principle that underlies the Dutch major hazards policy. Although no-one would probably object to a principle that requires efforts to be "reasonable", its actual application (looking beyond risk criteria or stand-still) proves rather problematic. In practice, plant owners appear reluctant to reduce risks beyond legal limits, and property developments often offset risk reduction efforts by plant owners. And when properties are built in closer proximity of chemical plants, nuisances such as noise or smoke become more noticeable. Plant owners thus gain little when risk contours shift towards their plants.[21] Conversely, local governments lose valuable building lands when they increase safety zones. It should thus come as no surprise that both plant owners and local governments have become reluctant to strive for risk reduction beyond legal limits (see also V&W-Council and VROM-Council, 2003).

A financial transaction effectively takes place when transporters of hazardous materials or plant owners reduce risks to the public and local authorities subsequently build up to the norms. An interesting example concerns the 2005 covenant between the LPG industry and the Dutch national government about the safety of (amongst other) LPG tanker trucks. The covenant obliges the industry to apply a heat resistant coating on LPG tanker trucks to reduce the probability of a hot BLEVE (boiling liquid expanding vapour explosion). The coating thereby shifts risk contours towards LPG fuelling stations (see the safety distances mentioned in Revi, the document that supplements the External Safety Decree, Bevi). Some local governments will thus receive a free lunch in terms of safety and/or opportunities for land-use.

When would it be reasonable to reduce risks beyond stand-still? From a cost-benefit perspective, risk reduction should be considered reasonable as long as marginal gains exceed marginal costs.[22] Other than on a case-by-case basis, risk reduction beyond stand-still could be considered *broadly* reasonable in case of intensifying demand for a safe society and/or technological process that make safer technologies less costly. Note that technological innovations not only influence the optimal level of risk but also the optimal allocation of the effort to mitigate risks. After all, when safer technologies become more cost-effective relative to safety zoning, the emphasis should shift from safety zoning to the adoption of safer technologies.

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[21] Source: representative of the process industry known to the author.

[22] It is assumed here, and throughout the remainder of this text, that first best optima are attainable. When a constraint prevents the fulfilment of an optimum condition, equating marginal costs to marginal gains will, in general, no longer maximize the social value of production. In fact, it might even move us further away from a second best optimum (Lipsey and Lancaster, 1956-1957). Suppose for instance that a hazardous plant uses apples and oranges as inputs and that the risk produced is only related to the quantity of oranges used. Due to technical difficulties, the factory can only operate using a minimal amount of apples. Welfare maximization might call for the use of this minimal amount, which would push the socially optimal amount of oranges, as well as the level of risk, above the level that would have been optimal had the constraint on the use of oranges not existed. Ensuring through regulations that the marginal costs and gains of risk reduction equals are equal would result in a quantity of apples being used below the quantity that would maximize social welfare.

In practice, reference to ALARA is only made to press for risk reduction. This asymmetry hardly seems reasonable. After all, when the gains of establishing or expanding hazardous plants are considerable, it could be reasonable to allow relatively high risks. A principle based on reason(able) can work two ways.

3.5 The allocation of the financial burden

3.5.1 Towards a compensation test?

The risks to the public caused by relatively unsafe plants with relatively large safety zones can be similar to the risks caused by a relatively safe plants with relatively small safety zones. So how much should we invest in safety zoning relative to plant safety? The most cost-effective measures would always be taken if markets were to operate perfectly. Opportunities for arbitrage ("free lunches") would soon by seized by profit-maximizing entrepreneurs. Consider for instance a plot of land that cannot be developed because of a hazardous plant nearby. When it would be beneficial to develop the land, the plant owner could buy the risky land at low cost, invest in the safety of his or her plant, and subsequently sell the now safe land at a profit. The reverse also holds: when it would be beneficial to expand the hazardous plant, its owner could buy off vulnerable objects, expand the factory, and all parties could be left with a net gain.

In real life, such mutually beneficial transactions will not always take place. Administrators that are faced with limited mandates and budgets might not be able to engage in these socially beneficial transactions. An obvious problem lies in transaction costs (as discussed in section 3.1), but agency costs could constitute another important obstacle: the interests of elected officials that act on behalf of a local population might not be aligned with those of society at large (as discussed in section 3.3.1).

The problem that arises when markets do not function properly is well illustrated by the Dordrecht case. Large volumes of hazardous materials pass Dordrecht by railroad as they are transported inland from the port of Rotterdam. While Dordrecht does not benefit directly from the transport of these goods, it does suffer from land-use restrictions (although Dordrecht received a 6 million euro subsidy to strengthen its emergency services). The municipality wanted transporters to invest in public safety, allowing houses to be built in close proximity of the railway line. Had the market operated perfectly, the municipality could have simply compensated transporters for reducing third party risks.

When, as in the Dordrecht case, bargaining solutions cannot be reached, societal cost-benefit analysis could be useful for illuminating trade-offs. A compensation test ("could beneficiaries compensate losers?") could perhaps resolve some of the tensions observed by the V&W-Council and VROM-Council (2003) between land-use and industrial activity. Cost benefit analysis draws attention to the fact that industrial activity has social value, that problems are reciprocal, and that risk is only part of the bigger picture. Cost-benefit analysis could also serve as a basis for deciding on compensation payments (financially or non-financially) to stimulate co-operation between those with opposing interests (see also section 3.1.6).

3.5.2 Towards 'internalising policies' to make 'polluters pay'?

In the Netherlands, plant owners do not have to pay for indirect land-use, i.e. land-use opportunities forgone through safety zoning. In 2004, the External Safety Directorate finalized a study into the effects of "internalising" the costs of indirect land-use. An internalising policy was defined as follows: "those responsible for external effects will to a greater or lesser extent be charged for these effects. The responsible actor will weigh the external effects in the decision to pursue an activity" (Pallas, 2004: 3). The proposed internalising policies were essentially about the entitlement as it was their main purpose to shift part of the financial burden for indirect land-use from the government to plant owners and transporters of hazardous materials. Rather than "internalising policies", such policies should be named "redistribution policies". Would such a redistribution policy indeed bring about efficiency gains?

Laying down rules under one entitlement and subsequently changing the allocation of rights could cause severe distortions. Consider for instance the following highly simplified case in which there are only two groups: the people that are exposed to third party risks, and the industry (a group composed of the owners of hazardous plants and all other beneficiaries of the industry's activities). Under a state of law that is permissive to industrial, third party risks, the exposed have to compensate the industry for reducing output to mitigate third party risks. Let us assume that private bargains can be reached. The end-result of bargaining depends on the willingness to pay (WTP) of the exposed, and the industry's willingness to accept (WTA). Let us assume that rules are made that lay down this end-result.

Table 5

Causes of the divergence between willingness to pay and willingness to accept

Cause	Description
Income effect	When demand for an asset is highly income elastic, willingness to accept (WTA) will exceed willingness to pay (WTP) (Hanemann, 1991; Willig, 1976).
Lack of perfect substitutes	Lack of perfect substitutes will cause WTA to exceed WTP (Hanemann, 1991). An individual's willingness to pay for a life-saving operation will equal his or her entire wealth. The person's WTA to forgo the operation will however be infinite.
Instant endowment	People generally view gains and losses differently (Kahneman and Tversky, 1979; Kahneman et al., 1990; Thaler, 1980). The entitlement determines the reference point for evaluating whether a change is perceived as a loss or a gain.
Existence value	The entitlement might not only assign a financial but also a moral responsibility (Boyce et al., 1992). WTP for the preservation of a forest is likely to be relatively low compared to the remuneration people would wish to receive for accepting its degradation or destruction.

Under the opposing state of law, individuals are entitled to a safe environment and the industry has to compensate exposed individuals for putting them at risk. The outcome of bargaining now depends on the industry's willingness to pay (WTP) and the willingness to accept (WTA) of the exposed. Because a strong divergence between WTP and WTA is to be expected (Table 5), it is unlikely that the bargaining solution under this state of law would be the same as the one under the opposing state of law. Put differently, it is unlikely that the previously defined rules would still be optimal.

Mishan (1971) presented a rather similar example of the influence of the disparity between the compensating and equivalent variation on resource allocation. He discussed optimum outputs under two opposing states of law: one state of law under which the victims of aircraft noise have to compensate those involved in air travel for reducing noise, and one state of law under which those involved in air travel have to compensate those that suffer from aircraft noise. When private bargains can be reached, the optimal number of flights will be greater under the state of law that is more permissive of aircraft noise.

The optimal stringency of industrial safety regulations depends on the entitlement when WTA and WTP diverge. Reallocating the financial burden for indirect land-use *after* the establishment of zoning and plant safety regulations could give rise to considerable inefficiencies. Whenever politicians wish to adopt such a redistributive policy, they should also reconsider the stringency of the safety zoning regulations that determine the amount of indirect land-use.

3.6 Conclusions

1. Industrial, third party risks are negative externalities: they are the side-effects of the production, storage and transportation of hazardous materials. If the market were to function perfectly, third party risks would be optimized through the profit-maximizing behaviour of individuals and firms (equity apart). There would then be little need for government intervention. But since the market for these risks does not function perfectly, government intervention can contribute to allocative efficiency.

2. According to the consequentialist utilitarian ethic that underlies this thesis, risk regulation is a balancing act. Neither too much nor too little risk (or regulation) comes to the benefit of society.

3. The polluter pays-principle does not always lead to the most efficient allocation of resources when the market does not function perfectly, i.e. when plant owners and the exposed population/governments cannot reach bargaining solutions.

4. Regulatory instruments should not be treated in isolation as their consequences often overlap. More stringent liability rules could for instance supplement relatively lenient societal risk criteria and vice versa.

5. The individual risk criteria in the field of external safety would be conformable to Bentham's greatest happiness principle when individuals would value disproportional exposures disproportionately.

6. The use of uniform FN-criteria for non-uniform cases is to confuse equity and efficiency. Societal risk criteria are related to efficiency rather than equity. Different FN-criteria should ideally apply to different cases.

7. The ALARA-principle captures the thought that risk regulation is a balancing act. Yet the common interpretation of the principle suggests a bias towards safer alternatives that will not always be reasonable. From a utilitarian perspective, risk reduction beyond stand-still is only reasonable as long as marginal benefits exceed marginal costs.

8. The use of the term "internalisation" for policies to make transporters of hazardous materials or owners of hazardous plants pay for indirect land-use is incorrect. Through (amongst other) zoning regulations, the regulator has already tried to optimize third party risks. A policy that shifts the financial burden for indirect land-use to plant owners and transporters of hazardous materials, while the stringency of zoning regulations is held constant, is unlikely to be optimal.

Chapter 4

The Dutch flood safety policy

As discussed in chapter 2, flood defence is an archetypical example of a public good. Without ways to avoid free-riding, people might have to resort to relatively cost-ineffective measures to protect themselves against floods. A means to avoid this would be to leave the provision of flood safety up to a government with the power to coerce (tax) its subjects. But how to establish a government (water board) in the first place? To clarify this issue, Homer Simpson will once again put in an appearance.

4.1 Flood defence: the provision of a public good

4.1.1 The case without free-riding

Homer Simpson has decided to leave Springfield and move to a peaceful and quiet part of the country. Unfortunately, this unspoiled land is prone to flooding. Let us assume that Homer can only do two things to reduce the risk of flooding: he could build a mound, or he could build a levee. As Homer is a rational utility-maximizer, he will spend every dollar where it buys him the greatest amount of flood safety. Both levees and mounds can be constructed up to different heights. Homer will heighten his mound or levee up to the point that the benefit of raising it no longer outweighs the effort (Figure 8)).[23] When Homer has to decide whether he wants to live on a mound or behind a levee, he will have to compare an optimal mound to an optimal levee.

[23] The marginal condition requires Homer to equate marginal costs to marginal benefits. Under downward sloping demand and diminishing returns, this equilibrium corresponds to an optimum. An additional condition for optimality is that Homer cannot be made better off by abandoning the flood prone area or by introducing other risk reduction strategies.

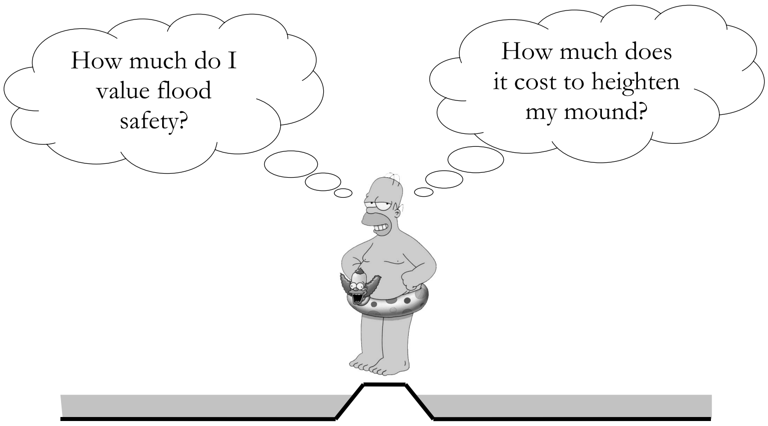

Figure 8 Homer on his mound

Now consider the case in which Homer is no longer alone in this flood prone area but joined by another person, Ned Flanders. Assume that they both value flood safety similarly. Homer and Ned could both build private mounds, but perhaps they could both be made better off if they were to pool their resources and construct a single levee.

While a mound can only protect the person that lives on top, a levee protects everyone that lives behind it. A levee therefore becomes increasingly attractive when the population at risk grows larger. The cost of levee construction can then be spread over a larger population, while the reduced probability of flood benefits everyone just the same: the marginal cost of extending flood protection to an extra individual equals zero. When nobody free-rides, the inhabitants of a flood prone area will thus construct a relatively safe levee, rather than a large number of relatively unsafe mounds (Figure 9).

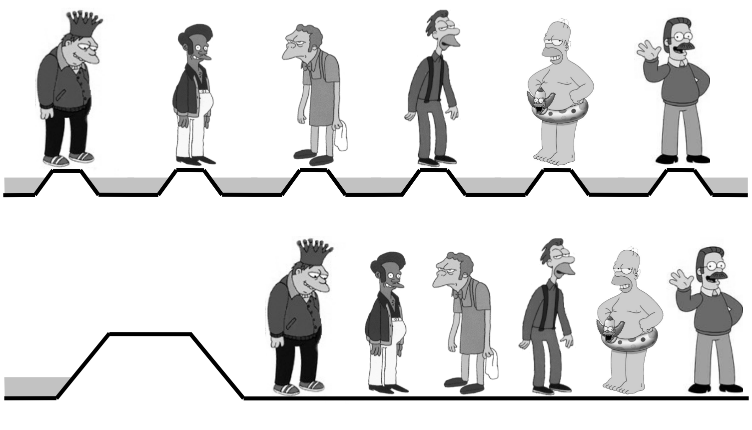

Figure 9 The people's level of protection on optimal mounds and behind an optimal levee (optimality is defined here in terms of risk-based design)

4.1.2 Government intervention

Free-riding could be prevented by establishing a government that raises funds through taxation.[24] Unfortunately, the decision to establish a government poses a coordination problem in itself. Without coercion, every resident of a flood prone area could decide not to participate in a collective arrangement, thus free-riding on the efforts of others. While coercion is needed to overcome the coordination problem, the choice for coercion raises a coordination problem as well.

A way to overcome this infinite regression would be to assume that individuals are not solely led by selfish material gain.[25] Letting go of the assumption that individuals act solely upon material self-interest is by no means inconsistent with the economic approach used here. As discussed by Wicksteed (1910), people may act out of love for family (a housewife buying food on the market for her family), God (a tentmaker making and mending tents out of love for God) or other, without invalidating economic theory.[26] In a cohesive society, free-riding comes at a cost: those that conspicuously try to profit from the efforts of others risk exclusion. The establishment of a water board with the power to coerce its subjects might thus be wholly consistent with individual utility maximization. The only assumption that has to be made is that the costs of (social) exclusion exceed the gains that could be secured through free-riding.

What are the net costs (or gains) that a person could expect to incur from the establishment of a water board? Buchanan and Tullock (1962) argue that the costs of collective action fall apart into external and bargaining costs. An individual is confronted with external costs when the water board implements policies that differ from the ones that the individual supports. The bargaining costs are the costs of reaching agreement. An individual's expected external costs will be lower when the voting rule that is used to reach collectively binding decisions approaches unanimity. After all, under unanimity rule, every individual can block the proposals that he or she considers undesirable. But reaching decisions will be difficult when every individual has to agree. Figure 10 schematically shows an individual's trade-off between external and bargaining costs for a population of N individuals. Under unanimity rule (n=N), external costs are absent but the cost of reaching agreement are maximal. Under dictatorship, the expected external costs are maximal but the costs of reaching agreement are minimal. The individual's optimal decision rule is found when the sum of the expected external and bargaining costs is minimal (n=n*).

When the preferences of the population diverge widely for the activity under consideration, people's optimal expected external costs and bargaining costs will be relatively high. In a strongly heterogeneous society, they might even be prohibitively high,

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[24] Note that the issue here concerns the funding of a public good, not the way it is provided: while a government might be called upon to raise funds, flood safety might still be provided by private enterprise (see also section 2.1.3).

[25] Arrow (1969) interpreted ethical and moral codes as means to overcome market failures. Similarly, in "'The moral basis of a backward society" Banfield (1958) offered lack of social cohesiveness as an explanation for the economic underdevelopment of the Italian village of Montegrano. The Dutch KNRM is a private emergency response organization that offers sea rescue to all that need assistance, including non-members. The organization funds its activities through donations. Even though free-riding is clearly an option, moral codes prevent this.

[26] This type of self-interest could be named communitarian self interest (after Orchard and Stretton, 1997).

causing individuals to go their own separate ways. But when the preferences of the individuals are broadly similar, the costs of association will be relatively low. Floods can affect all residents of a dike ring. When collective decisions merely concern water management, it thus seems likely that the (individual) benefits of the establishment of a government will exceed the (individual) expected costs.

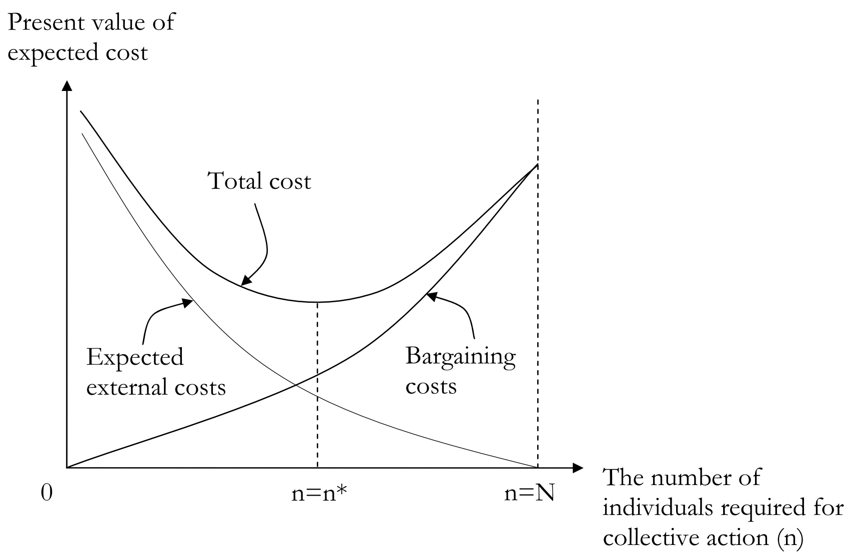

Figure 10 The trade-off between external and bargaining costs (adapted from Buchanan and Tullock, 1962: 71)

Given the trade-off between external and bargaining costs, the residents of a flood prone area may well unanimously decide to take future decisions under less than unanimity rules, as well as decide to vote for representatives that act on their behalf. Such decisions can be wholly consistent with the assumption that individuals behave as rational utility maximizers.

4.2 Optimizing flood risks[27]

The Flood Defence Act (1996b) lays down safety standards for all primary flood defences in the Netherlands. These standards have been derived/rationalized by cost-benefit analyses (Van Dantzig, 1956; Van Dantzig and Kriens, 1960). As such, the Dutch standards for flood protection are explicitly based on an attempt to balance the costs and benefits of risk reduction.

[27] An excerpt of this section has been published as Jongejan et al. (2008).

The Flood Defence Act lays down rules related to flood *probabilities*, not to the *consequences* of floods. A convincing argument for this focus on flood prevention lies in its cost-effectiveness relative to measures to reduce the consequences of floods through e.g. safety zoning or an extensive disaster response organization (I will return to the latter in chapter 9). And when it is most cost-effective to invest in prevention, every euro should, from an efficiency perspective, be spent on flood prevention.

The report and eponymous article "Changing estuaries, changing views" (Saeijs et al., 2004; Smits et al., 2006) criticize a flood risk mitigation strategy that relies on flood defences. The suggested alternative could be summarized as a proposal to leave deltas untouched and to adapt socio-economic activity to the natural system. This could be a viable flood protection strategy in exceptional cases such as the Yellow River delta, a relatively untouched prograding deltaic system. But the realities of coastal morphology and economic life will often necessitate a compromise between a vibrant, untouched deltaic region and a safe and prosperous society. The choice between these two extremes should, at a minimum, be based on a realistic assessment of socio-economic and environmental impacts, as well as physical (here: morphological) conditions. Several recommendations by the authors of "Changing estuaries, changing views" however fail that test. The criticisms of the Dutch present-day flood defence strategy, as well as the suggested solution to leave deltas untouched, rest on assumptions that are highly disputable.

The authors of "Changing estuaries, changing views" rightly note that "From a socio-economic point of view, the impression of safety bestowed by the massive dikes, invited people to invest money behind them" (Smits et al., 2006: 343). They therefore recommend not to construct dikes and to leave deltas untouched (Smits et al., 2006: 353). Investments in low-lying regions indeed increase potential damage. But should investments in delta regions also be interpreted as an unintended and detrimental side-effect of dike strengthening? Stimulating or safeguarding economic growth has been and still is a centrepiece of government policy. Such a policy is a major drive for human intervention in delta regions. The lower the probability that individuals lose their lives and livelihoods in floods, the more attractive a delta becomes (ceteris paribus).

When governments are supposed to act upon the preferences of their individual citizens, flood protection and subsequent socio-economic development should be encouraged rather than remedied. As discussed, flood defence is the archetypical example of a public good: it is characterized by non-rivalry and non-excludability. No matter how many people are protected, a dike protects everyone just the same (although damages may differ due to e.g. topographical effects). A flood defence system therefore becomes increasingly attractive when the population within its confines grows larger. While potential damages increase when people invest in areas protected by dikes, subsequent investments in flood protection result in a per capita decrease in flood risks and costs of flood protection.

Although the authors of "Changing estuaries, changing views" rightly note that "tens of millions are spent each year to keep the civil-engineering constructions in good condition" (Smits et al., 2006: 345), these expenditures are fairly modest considering the sizeable population and valuable assets that the Dutch flood defences protect. And although 60% of the Netherlands lies below sea level, annual spending on flood protection is only 0.15% of GDP (RIVM-MNP, 2004). Despite the low annual expenditures on maintaining and upgrading the Dutch flood defences, the level of flood safety provided is exceptional compared to standards elsewhere.[28] The suggested alternative to flood defence, i.e. leaving deltas untouched and adjusting socio-economic processes to the natural system, would certainly compromise economic growth. And secondly, it would by no means be without investment or maintenance cost as infrastructures and houses that can cope with regular flooding are more expensive than those that cannot.

But what about the future? The sea level rises and the land subsides. Indeed, "the combination of the rising sea level and subsidence of the reclaimed land (particularly the peat areas) dramatically changed the difference between sea and land. Most polderland now lies far below the level of the sea" (Smits et al., 2006: 343). Could the speculative conclusion therefore be supported that "a delta without dikes is safer than a delta with dikes, because natural processes will weaken the effects of extreme storm floods" (Smits et al., 2006: 352)? Would natural sedimentation processes indeed "provide a durable alternative to the unreliable dikes" (Smits et al., 2006: 352)?

At least for large parts of the Netherlands, the answer is no. Although sedimentation would cause the land to rise, this effect would be nullified by the rates of erosion and sea level rise. Without human intervention, the Netherlands would sink rather than rise relative to the sea. To prevent the Dutch dune coast from decline, large volumes of sand are dumped annually onshore and offshore. Geological reconstruction of the Dutch delta including its estuaries (the Waddensea and the Zeeland estuaries) teaches us that, although sedimentation has occurred in the central Almere lagoon between 6000 and 4000 years BP primarily through marine sediment feeding under high sea-level rise rates (Beets et al., 1992), it has not been strong enough to elevate the land above mean sea-level. Another illustrative example concerns The Biesbosch, a freshwater tidal natural reserve that was created in 1421 by the St. Elizabeth flood. Despite its open connection to the sea from 1421 to 1850, it still lies only 0.5m above mean sea level, offering little protection against extreme floods. Although estuaries provide sediment accommodation space under sea-level rise (Cowell et al., 2003), it is expected that increasing rates of sea-level rise will result in the drowning of estuaries, rather than in an equilibration of the subaqueous morphology (Van Goor et al., 2003). And even when land would rise with the sea, low-probability, extreme storm surges could still have devastating consequences without flood defences. A storm surge with an exceedance frequency of 1/10.000 per annum (which what the primary flood defences that protect dike ring Central Holland should be able to withstand) could also hit next year, well before sedimentation has elevated the land.

But even with massive flood defences in place, there will always be a probability, however remote, that things go horribly wrong. Yet the probability of dike failure is by no means a fixed value. A dike that is, say, one kilometre wide and fifty meters high would be extremely reliable. But it would also be extremely costly. The key question, as with any flood protection strategy, is how much we are willing to invest in risk reduction. Under the definition of a social improvement that underlies this dissertation, the answer to this question depends crucially on (aggregate) costs and gains. The balance of the costs and benefits of alternative solutions is likely to change over time. Scientific progress (e.g.

[28] That said, present standards for the Dutch primary flood defences seem outdated (see also RIVM-MNP, 2004) and a considerable percentage of the Dutch primary flood defences fails to meet even these standards (Ministry of Transport, Public Works and Water Management, 2006).

better knowledge about the effects of interventions on ecosystems), technological developments (e.g. new technologies that reduce environmental harm), and changing preferences (e.g. a stronger willingness to pay for environmental quality) all influence this balance.

In densely populated areas, where socio-economic pressures are considerable and growth rates are in the order of 2% per annum, it seems unlikely that it would often make economic sense to adjust modern socio-economic life to the slow pace of natural processes rather than the other way round. In sparsely populated areas however, the view of "a society in balance with nature" (Smits et al., 2006: 351) might be more appropriate. But again, much depends on physical conditions, technological possibilities, and the realities of socio-economic life.

4.4 Conclusions

1. The provision of flood safety in the Netherlands concerns the provision of a public good.[29] The Dutch standards for flood defences are amongst the few that are explicitly based on an attempt to balance the marginal costs and benefits of risk reduction.

2. Age-old solutions such as the construction of levees and flood defences seem increasingly less popular. While innovations might perhaps be advantageous, a proper comparison of alternatives should be based on opportunity cost. By selecting the most cost-effective measures, people can buy the greatest amount of flood safety and/or spend more on other socially desirable projects.

3. Recurring themes in debates about flood safety are that dikes are never safe and that they worsen rather than reduce flood risks. The first claim is undoubtedly true, but it holds equally for its alternatives. Proposals to leave deltas untouched and to rely on natural sedimentation presuppose morphological conditions that would be extremely unlikely in large parts of the Netherlands. Moreover, adapting infrastructures and properties to regular flooding, and/or having to regularly halt the economic process to weather a flood would be a costly affair economically valuable regions.

[29] River floods can also be analyzed within the framework of negative externalities because the actions of those living upstream can influence the risks to those living downstream.

Chapter 5

Comparing the Dutch industrial and flood safety policies

How does the Dutch industrial safety policy compare to the Dutch flood safety policy? What opportunities for mutual learning could be identified?[30]

5.1 Introduction: comparing regulatory practices

Governments have responded in various ways to the challenges posed by industrial and natural hazards. The regulatory arrangements that exist today are generally the result of a long process of "muddling through", influenced by numerous contextual factors, historical events and pure coincidences (Lindblom, 1979; Lindblom and Woodhouse, 1993). Comparative analyses of government policies can improve our understanding and facilitate learning from experiences elsewhere. Such studies often concern cross-country comparisons of practices within a single policy domain. Comparative analyses have for instance illuminated the different ways in which EU-member states have implemented the land-use planning provisions of the Seveso Directives (Christou and Mattarelli, 2000; Papazoglou et al., 1998). Others have contrasted the development of regulations in different countries to analyze the influences of institutional variables. A recent comparative study of the major hazards policies in the Netherlands and the United Kingdom for instance showed how different legal traditions have led to several fundamental differences (Ale, 2005). Such studies indicate that one should be cautious when attempting to extract best practices from cross-country comparisons without concern for institutional or cultural variables.

But other than comparing practices within a single policy domain across different countries, we could also compare practices in different policy domains within a single country. Such comparative studies would allow us to evaluate the consistency of regulatory practices within countries, and help us to identify opportunities for mutual learning without having to worry too deeply about e.g. legal traditions and the

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[30] An excerpt of this chapter has been published as part of Jongejan and Ale (2008).

institutional outlines of different states. Yet such an approach also introduces important new difficulties. For a meaningful comparison of regulatory practices across policy domains, there obviously has to be a strong common denominator. This chapter presents a comparative analysis of the Dutch industrial and flood safety policies. These policies are both concerned with low-probability, high impact events that are caused by the failure of socio-technological systems. Considerable parallels can be drawn between industrial accidents and floods in the low-lying Netherlands. Rupture or breach of a physical barrier (dike or e.g. pressure vessel) could cause loss of containment. And this, in turn, could cause considerable physical damages.

When comparing of regulatory arrangements, we could choose from a wide variety of analytical frameworks. The choice for such a framework is essentially the choice for a lens to look through (Parsons, 1995). It determines the way we view and interpret the world around us. We might for instance analyze cultural aspects that influence government responses to risks (Douglas and Wildavsky, 1983), attempt to trace regulatory practices back to historical events (Ale, 2002), or consider the economic rationales for and impacts of government interventions. It is the latter approach that is taken here.

5.3 Commonalities and differences

the domain of external safety, quantitative risk criteria are used for licensing purposes. And in the domain of flood safety, exceedance frequencies of water levels are used to design and maintain flood defences. On the basis of such a superficial comparison of regulatory practices in domains of external and flood safety in the Netherlands, one is likely to conclude that commonalities are few and far between. But beneath the surface, there is considerable common ground.

The Dutch industrial and flood safety policies are both firmly risk-based. The probabilistic design standards for the Dutch primary flood defences as well as the FN-criteria that are used to evaluate industrial risks can be linked to a cost-benefit perspective: despite their different appearances, they both intend to maximize the social value of production. That is, they both attempt to optimize (rather than minimize) risks to the public. Yet there are also several differences that provide opportunities for mutual learning.

First, while different standards for flood protection apply to different dike rings, equal societal risk criteria apply to establishments and transport kilometres of all sorts and sizes. A differentiated set of societal risk criteria might do more justice to the differences between the marginal costs of risk reduction in different cases. It is striking in this respect that Schiphol airport was allowed to exceed the societal risk criterion that was established for industrial establishments because it would be too costly for Schiphol to meet this criterion (Ale and Piers, 2000).

Second, while the Dutch industrial safety policy relies on individual risk criteria to prevent disproportional exposures, the Dutch flood safety policy lacks such legal limits. Individual risks related to floods are determined by numerous variables, such as the failure probabilities of individual dike ring sections, the areas affected by failures of dike ring sections, and the local circumstances that influence flow velocities, inundation depths, and rise rates (see for instance Jonkman, 2007). Estimating individual risks within dike rings requires advanced risk modelling techniques. Within the FLORIS-project (see appendix IV), the failure probabilities of dike ring sections and the consequences of their failures (in terms of loss of life) have been estimated for three dike rings: Northeastpolder (dike ring 7), Central Holland (dike ring 14), Land van Heusden/De Maaskant (dike ring 36). As shown by the individual risk map for dike ring 36 (excluding evacuation), individual risks are by no means constant within dike rings (Figure 11).[31]

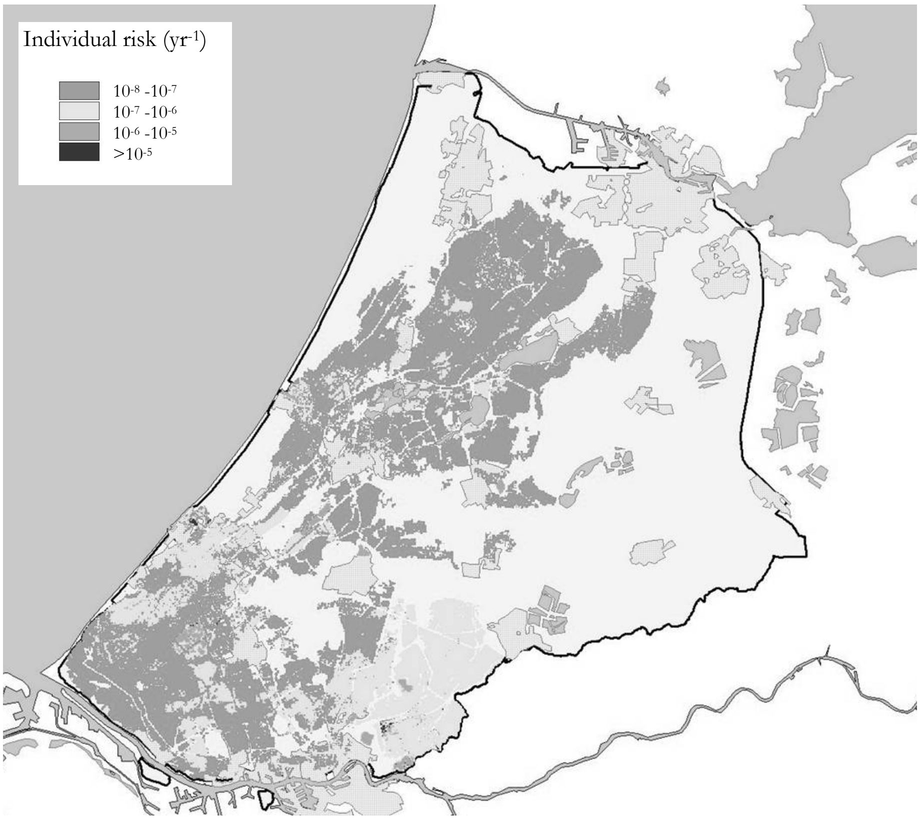

Figure 11 Individual risk estimates for dike ring 14 (Jonkman, 2007: 268)

[31] Individual risk estimates could include or exclude the probability of successful evacuation. When probabilities of successful evacuation are in the order of 10%, the resulting differences will be within one order of magnitude. For evaluations of spatial plans and/or evaluations of the safety of flood defences (with consequences that involve start-up costs), the use of individual risk criteria that exclude the effect of evacuation seems preferable. Changes in for instance congestion could otherwise lead to risk evaluations that would require costly investments in flood protection and/or the removal of vulnerable objects.

When flood defences are up to standard, the individual risks of those living behind the primary flood defences are likely to be low (<10^{-5} per year). After all, when failure probabilities of dike rings are in the order of 10^{-3} per year, and average conditional death probabilities are in the order of 1%, individual risks around or below 10^{-5} per year are to be expected (bearing in mind that the failure of an individual dike ring section is lower than the failure probability of the entire ring and that not all areas are not equally affected when a particular dike ring section fails). But given the wide variety of factors that influence individual flood risks in dike rings, it would be interesting to put this expectation to the test when more results of the FLORIS-project come available.

A third important difference between the two policy domains is that the Dutch industrial safety policy uses societal risk criteria to control the probability of large numbers of fatalities (as a proxy for social disruption and trauma). The Dutch flood safety policy lacks such criteria: probabilities of dike failure are independent of potential loss of life. Increases in societal risks have to be motivated in the field of industrial safety. But flood safety standards have not been tightened or formally reviewed in the light of changes in societal risks, even though the Dutch population has more than doubled since 1953. An FN-curve for floods is shown in Figure 12.

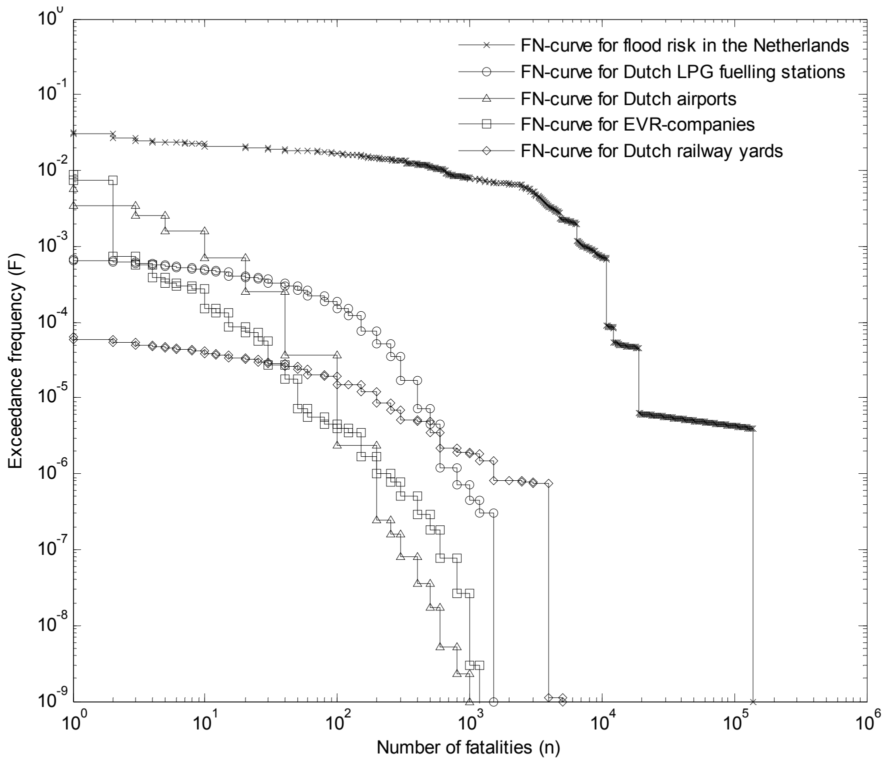

Figure 12 FN-curves for floods (average curve) and various other hazardous activities in the Netherlands (data: RIVM, 2001)

Figure 12 also shows FN-curves for Dutch LPG fuelling stations, the transport of hazardous materials by road, Dutch airports, EVR-companies[32], and Dutch railway yards.[33] Each of these FN-curves is subjected to considerable uncertainty as the quantification of accident probabilities and their consequences involves numerous assumptions. But as they were derived from the risk estimates that play such an important role in the Dutch external safety policy (FN-curves for individual establishments and transport kilometres), they do not lack practical significance.

The FN-curve for floods is also subjected to considerable uncertainty. Although the FN-curve shown in Figure 12 might seem pessimistic, it is based on the (optimistic) assumption that the failure of one dike rings precludes the failure of another. But when there are dependencies between the failures of different dike rings, exceedance frequencies of low-consequence events will go down, while the probability of a severe loss increases (see also Appendix IV). All FN-curves shown in Figure 12 are based on the assumption that accidents are mutually exclusive. It indeed seems unlikely that two industrial or transport accidents will occur at exactly the same time (domino effects aside). But when it comes to floods, an extreme event that causes floods in several dike rings is not unthinkable.

The high level of societal risk for floods in comparison to the level of societal risk for industrial activities does not automatically imply that budgets should be reallocated to improve flood safety at the expense of industrial safety. When the marginal cost of reducing societal risks related to floods exceed the marginal cost of reducing societal risks related to industrial accidents, the optimal solution would call for greater societal risks related to floods (all other things being equal).

The fact that the Dutch flood safety policy lacks societal risk criteria does not mean that loss of life is completely ignored. Cost-benefit analysis can be, and is, used to derive/rationalize flood safety standards. Loss of life is monetized and included in the financial balance. Yet the value function that is used is linear, while the FN-criteria that are used in the Dutch industrial safety policy are averse to larger numbers of fatalities. If non-linear, e.g. quadratic, value functions were to be used to remove this inconsistency, loss of life could come to dominate the outcomes of cost-benefit analyses for the Dutch flood defences.[34] If, for instance, a single fatality is valued at 1 million euro, 100 fatalities are valued at 10 billion euro rather than 100 million euro when a quadratic value function is used. Other than including loss of life in a single financial balance, decision makers could also be presented financial balances together with FN-curves for different flood defence standards. It would then be left up to decision makers to weigh (changes in) FN-curves against (changes in) net present values of expenditures.

A final important difference between the Dutch industrial and flood safety policies concerns the government's roles in dealing with industrial and flood risks. Under the Environmental Law (which is where the Dutch major hazards policy falls under), the

[32] EVR-companies are those companies that deal with large quantities of hazardous substances and that are therefore required to submit a safety report to competent authorities.

[33] The FN-curves are based on the risk estimates that were available to the National Institute for Public Health and the Environment (RIVM). This set need not be entirely comprehensive.

[34] The argument could, of course, also be reversed: why not drop the FN-criteria that are used in the field of external safety and consider the expected value of the number of fatalities instead? For low-probability events, the expected value is typically negligible. And it is unlikely that a risk neutral evaluation captures the anxiety that large accidents generally cause (see also chapter 7).

government acts on behalf of the endangered population, just as it does in the field of flood safety. But the government attempts to remedy a special case of joint supply in the field of industrial safety, whereas it acts as the provider a public good in the field of flood safety. When it comes to industrial safety, the government attempts to optimize the behaviour of market participants through (amongst other) a permit system. By contrast, the Dutch flood safety policy is about streamlining the relations between a population and a government that acts on its behalf. This difference is important when evaluating claims that people living in flood prone regions should take greater personal responsibility, as in the domain of industrial safety.[35] Although the argument for greater personal responsibility is perhaps defensible for people living in floodplains, it seems unreasonable for those living behind primary flood defences. Advocating greater personal responsibility implies that people currently do not take their responsibility. This hardly seems a defensible position. The construction of flood defences led to the establishment of the first democratic organizations: the water boards. These specialized bodies could more efficiently and effectively deal with flood risks than individuals themselves. People that live behind flood defences take their responsibility by contributing to government bodies that construct and maintain flood defences on their behalf.

5.3 Conclusions

1. Comparative studies can put regulatory practices into perspective and help identify opportunities for mutual learning. At first sight, policies in different domains might seem to have little in common. But beneath the surface, there could be considerable common ground.

2. Standards for the Dutch primary flood defences vary throughout the country, depending largely on the costs and gains of risk reduction. But equal societal risk criteria apply to hazardous establishments and transport kilometres of all sorts and sizes. A differentiated set of societal risk criteria could do more justice to the differences between the marginal costs of risk reduction in different cases.

3. The Dutch industrial and flood safety policies are both firmly risk-based. But while the FN-curves that are used in the field of industrial safety are averse to larger numbers of fatalities, the cost-benefit analyses for the Dutch flood defences use linear value functions for loss of life.

4. In the domain of industrial safety, the national government acts as a *regulator* that enforces the rules of the game that individuals, firms and local governments have to play by. But in the domain of flood safety, the government plays the role of the *provider* of a public good.

[35] Stimulating people to take private action could only be efficient if those living in flood prone regions were to expect to be fully remunerated by others when disaster strikes.

PART II

Evaluating risks to the public

Chapter 6

Cost-benefit analysis and the evaluation of public safety

How can cost-benefit analysis (CBA) be used within the context of risk appraisal? How is CBA currently used for the evaluation of policies that concern health, safety and the environment?

6.1 Introduction

There are numerous textbooks and guides on the use of cost-benefit analysis (CBA) for the appraisal of policy and project proposals (e.g. Eijgenraam et al., 2000a; b; HM Treasury, 2003; Pearce et al., 2006; Pearce and Nash, 1982). This introduction therefore only highlights the basic principles of CBA.[36] Cost-benefit analysis involves the aggregation of a policy or project's gains and losses relative to some reference alternative to devise a net financial balance.[37] When gains and losses are distributed over time, the opportunity cost of capital (or time preference rate) should be taken into account. The net present value of a continuous stream of gains and losses equals:

$$NPV = \int_{t=0}^{t=T} C_t e^{-rt} dt \tag{6.1}$$

[36] Multi-criteria analysis (MCA) may seem rather similar to cost-benefit analysis at first glance. In a nutshell, it involves the scoring of a project on a selection of variables. Scores on these variables are then weighed subjectively and added to come up with an overall project score. MCA and CBA need not be rivals: they can also be used as complements (see e.g. Sijtsma, 2006). MCA might for instance be used as a follow-up to a CBA (or cost-utility analysis) to compare a financial balance to a balance of intangibles.

[37] The use of cost-benefit analysis for the evaluation of public policy is not as objective or value-free as is often suggested (see also section 1.4).

Where: NPV = net present value (euro); C_t = cash flow at time t (euro); r = discount rate (per year); T = time horizon (year).

The use of cost-benefit analysis for the appraisal of public policy is not uncontroversial, especially when it comes to policies that concern health, safety and the environment. Should we value non-market goods in money terms so that we can compute a single financial balance? Can we meaningfully reduce the multiple qualities that determine the value of non-market goods to euros or dollars? Or should we just present the balance of intangibles separately and proceed using e.g. multi-criteria analysis? This chapter deals with these, and other, questions.

An overview of the main criticisms of cost-benefit analysis is presented first. The remainder of this chapter then deals with current practice: how comparable are the results of cost benefit analyses in the Netherlands? Theoretically, there would be little difficulty to attract the external capital needed to pay for investments with a positive net present value. But when capital is in short supply, projects should be prioritized on the basis of their net present values (Brealey et al., 2006). Government bureaus typically operate under a budget constraint. Under such a constraint, a positive net present value is no longer a sufficient condition for a project to be desirable: to squeeze the most out of the available budget, the project then also has to outperform other positive NPV projects. This makes the comparability of cost-benefit analyses all the more important when it is used by public sector bodies to appraise policy proposals.

6.2 Answering the critics of cost-benefit analysis

6.2.1 The social discount rate

A relatively high discount rate implies that future costs and benefits will hardly influence today's decisions. As Page puts it: "Because of its political consequences, the government rate of discount becomes a strategic number" (Page, 1977: 156). Unfortunately, economists differ considerably in their opinions on the appropriate discount rate for public investments (Weitzman, 2001). This was recently illustrated by debates over the discount rate that was used in the Stern Review on the economics of climate change (Stern, 2007). The Review concluded that carbon dioxide emissions should be immediately and drastically reduced. This alarming conclusion would not have been reached had a more conventional (higher) discount rate been used (Nordhaus, 2007; Odling-Smee, 2007). Debates about the social discount rate seem to revolve mainly around two issues: (i) the discounting of long-term (environmental) impacts, and (ii) the discounting of health impacts.

Long-term discounting often raises concerns over intergenerational equity. Cost-benefit analyses are based on the potential compensation test. According to Freeman (1977), it would be inconsistent to distinguish between present and future populations on the issue of potential versus actual compensation. Others however propose to avoid decisions that could harm future generations (e.g. Stern, 2007). Even if funds were to be set aside to compensate future generations, it would be impossible to know a-priori whether the amount of compensation would suffice. Future generations might for instance value environmental quality considerably higher than current generations. When a relative price level is expected to change over time, the general price level should be deflated or inflated depending on the sign of change. The cost of radioactive waste management might for instance fall at a faster rate than the general deflator due to scientific progress. But when damages are expected to increase strongly non-linearly, prices might have to be inflated. The UK's Green Book lists various factors that should be considered when assessing potential changes in relative prices: scarcity, substitutability, non-linearity, increasing competition and economies of scale (HM Treasury, 2003-26). But although changes in relative prices and discounting can have similar effects on the present value of future costs and benefits, the two should not be confused and treated (discussed) separately.

It is sometimes proposed to adopt a declining discount rate[38] because the effective, probability weighted net present value of gains and losses tends to the value of the lower bound of the confidence interval under uncertainty concerning the discount rate (Weitzman, 2001). The UK's Green Book also proposes the use of a declining discount rate for the appraisal of policies, programmes and projects: the discount rate falls after 30 years from 3.5% to 1% for the costs and benefits generated after 301 years (HM Treasury, 2003). A non-declining discount rate of 2.5% is used in the Netherlands.[39]

Now let us consider the discounting of health effects. Some propose the use of a lower discount rate for (monetized) health impacts than costs because people might value health differently in the future[40] (e.g. Van Hout, 1998). Others, however, point to the inconsistencies this may cause (Weinstein and Stason, 1977). A well known inconsistency concerns the delay paradox: when a lower discount rate is used for health impacts than costs, a program should be delayed indefinitely (Keeler and Cretin, 1983).

In practice, the social discount rate is based either on the social time preference rate or the opportunity cost of capital (Pearce and Nash, 1982). The first refers to the rate at which individuals collectively discount future costs and benefits. This is the course followed in the UK (HM Treasury, 2003). The opportunity cost of capital approach considers an investment's revenues relative to those of the available alternatives (in real terms). This is the course followed in the Netherlands (Risk Appraisal Committee, 2003).

Staying with the opportunity cost of capital approach that is used in the Netherlands, a difficulty arises concerning the degree to which governments compare to private firms in their ability to deal with risks (risk here refers to uncertainty concerning the cash-flows that a project or policy generates). The Arrow-Lind theorem asserts that the government should be treated as a risk-neutral agent (Arrow and Lind, 1970): If governments were to incidentally raise and lower taxes to maintain balanced budgets, individual taxpayers would only be confronted with minor fluctuations in their disposable incomes. The position that the government should be treated as a risk-neutral agent has however been challenged. Public investment projects can entail considerable cost per person (Klein, 1997). Moreover, the Arrow-Lind theorem presupposes that a project's revenues (losses) are uncorrelated with national income. The Dutch Risk Appraisal Committee has adopted the consumption-based capital asset pricing model (CCAPM), a generalization to the Capital Asset Pricing Model (CAPM), to calculate risk premiums. The degree to

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[38] The discount rate can be constant or a function of time t. For a declining discount rate $dr/dt<0$.

[39] The (risk-free) discount rate for public investments was lowered from 4% to 2.5% in 2007 by the Minister of Finance.

[40] Again, the issue seems to concern changes in relative prices.

which citizens have to be remunerated for government risk-taking then depends on the covariance between returns/costs and a consumption index.

Debates about "the" discount rate to be used for the appraisal of public policy are unlikely to be settled anytime soon. While the choice for any social discount rate will stir up discussion, sensitivity analysis can provide useful insights about the robustness of a project's net present value to time preferences. Uncertainty about "the" discount rate thus need not render cost-benefit analysis useless as method to inform decision makers about the consequences of alternative courses of action.

6.2.2 Defining a risk metric

As discussed by the Health Council of the Netherlands (1995; 1996), risk is more than just a number. Defining risk inevitably involves a set of subjective, and therefore disputable choices (Fischhoff et al., 1984). Do we for instance define risk in terms of loss of life, material damage, or their perceived severity? These choices can have important consequences for risk decision making. As Slovic et al. (1999) put it: "Whoever controls de definition of risk controls the rational solution to the problem at hand".[41] Consider for instance the Dutch individual risk criterion for land-use planning in the vicinity of major industrial hazards. Individual risk is defined as a death rate. But what about the probability of severe injury? As deaths and injuries appear poorly correlated for industrial and transport accidents (Appendix III), the choice for another consequence indicator than death might in some cases yield strongly different acceptability judgments.

6.2.3 The estimation of intangible effects

Substitution can cause severe difficulties when it comes to the estimation of the net impact of a policy or project on loss of life (or other non-market goods). Phasing out air travel would undoubtedly reduce the risk of plane crashes. But when people switch to different transport modes, they might end up in car crashes and cycling accidents. Similarly, when the results of a cost-benefit analysis were released that showed a positive net present value for a policy to phase out LPG as a car fuel out of concern for public safety (Ecorys-NEI, 2004), the LPG industry responded by raising awareness for (amongst other) the potential increase in the number of deaths due to air pollution if motorists were to switch to more polluting car fuels.

Substitution poses much less of a problem when it comes to market goods. When secondary markets operate perfectly, the impact of a policy on primary markets is all we have to consider for estimating welfare effects. Demand curves then already reflect the availability of substitutes (see also Ecorys-NEI, 2004). Unfortunately, the same logic cannot be applied to non-market goods. Arbitrary cut-offs will often be needed to estimate "net" health effects.

6.2.4 The valuation of intangibles

To be able to include intangibles in a financial balance, their value has to be expressed in money terms first. This section deals with the monetary valuation of loss of life, a particularly controversial matter. Regulatory agencies have defined numerous benchmark

[41] Apart from the issue raised by Slovic et al. 1999), the concept of rationality also becomes troublesome when it comes to social choice, see section 1.4 and chapter 11.

VSLs[42] to be used in cost-benefit analyses. VSL-values used by US regulatory agencies (1985-2000) range from 1 to 6.3 million USD (converted to 2000 prices) (Viscusi and Aldy, 2003). The UK's Health and Safety Executive (HSE, 2001) proposed a value of 1 million pounds and a figure twice as high if death was caused by cancer. Official values for the prevention of fatalities from road traffic accidents range from about 250.000 to about 3 million euro (2002 prices) for north-west European countries (Rosebud, 2004). Where do such values come from?

Economists have developed a number of methods to infer money values for (the prevention of) loss of life. These can be grouped under three broad headings: (i) stated preference methods, (ii) revealed preference methods, and (iii) non-behavioural methods. A notable example of a stated preference method is contingent valuation. It is a survey-based technique in which respondents are asked to value (the preservation of) an intangible in a hypothetical market setting (Arrow et al., 1993). Respondents could for instance be asked to state their willingness to pay for a given reduction in the probability of fatal traffic accidents. These results can then be used to calculate VSLs.

Revealed preference methods derive VSL-estimates from observed behaviour. The hedonic pricing method for instance tries to isolate the effect of risks to life on product prices, wages, or property prices. A meta-analysis of hedonic VSL-estimates for the US labour market showed VSLs in the range of 4-9 million USD and a median value of about 7 million USD (Viscusi and Aldy, 2003). VSL-estimates can also be obtained using regulatory revealed preference methods. These methods consider the net cost of regulations and their impact on public safety. A study by Tengs et al. (1995) reported the cost of saving a life year for 500 life-saving interventions. These cost vary over orders of magnitude, between as well as within accident categories.

Non-behavioural methods are commonly based on people's contribution to the national economy (human capital approaches), sometimes considering life quality as well. A notable example of the latter concerns the Life Quality Index methodology (Nathwani et al., 1997; Pandey and Nathwani, 2003; 2004; Rackwitz, 2004). The method is based on the trade-off between leisure time and wealth: risk reduction raises life expectancy but has to be paid for through extra labour.

As discussed, reported VSL-estimates vary over orders of magnitude, with most in the order of 1-10 million euro in industrialized countries (Ball et al., 1997). It should be noted that "the" VSL does not exist: VSLs depend on initial risk levels and the changes under consideration (De Blaaij et al., 2003; Vrijling and Van Gelder, 2000). Variations between VSL-estimates are also caused by the fact that different valuation methods measure different aspects of (loss of) life, such as people’s use value or their intrinsic worth. By using single, fixed values or valuation methods, analysts would essentially take the place of political decision makers. It therefore seems best to perform sensitivity analyses, and to leave the choice for a valuation method (or the choice not to value intangibles in money terms) to decision makers. In an extensive cost-benefit study about ways to reduce the risks posed by ammonia and liquefied petroleum gas (LPG) (TNO et al., 2004), it was left up to politicians to decide whether a balance of intangibles weighed up against a negative net present value of financial gains and losses. This practice does not appear unreasonable. After all, when CBA is used as a means to *inform* decision-makers, its results should be offered in a manner that suits their information needs.

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[42] VSL stands for the Value of a Statistical Life.

6.2.5 The incommensurability critique

The incommensurability critique implies that the multiple attributes that determine an item's worth cannot always be meaningfully reduced to the same single unit of value (Raz, 1997). For market goods, this reduction is widely accepted. But for non-market goods, it is not. Although the incommensurability critique asks us to critically think about the monetary valuation of intangibles, it does not ask us to abandon cost-benefit analysis altogether. Incommensurability does not have to imply incomparability (Chang, 1997; Raz, 1997). One might for instance prefer the preservation of a nature reserve over a lavish vacation without ever having to define a shared numéraire such as dollars or cookies. By listing incommensurables separately, cost-benefit (or: cost-utility) analyses can still provide useful information to decision makers that have to compare alternative courses of action.

6.2.6 The overdeterminism critique

The overdeterminism critique holds that it is it is impossible to know all there is to know in our highly complex world (see also Lindblom, 1979; 1990; Lindblom and Woodhouse, 1993). Cost-benefit analysis, it is argued, therefore only produces a false sense of certainty concerning an uncertain future. While fully comprehensive assessments indeed seem impossible in a world where everything is related to everything else, most things fortunately seem only weakly related to other (Simon, 1983). But in the light of bounded rationality, it seems unreasonable to trust economists to be able to perform detailed cost-benefit analyses entirely on their own. The quality of cost-benefit analyses is likely to benefit strongly from stakeholder participation. A notable example concerns an elaborate cost-benefit study about measures to reduce the risks associated with the production, storage and transport of hazardous materials (KPMG et al., 2004). Industry representatives, local governments, environmental groups, and individual firms formed a sounding board that met regularly to discuss input, assumptions, and outcomes. Not only did this procedure improve the quality of inputs and analyses, it also led to consensus over key issues.[43] As the example shows, the mere task of jointly performing a cost-benefit analysis might help build consensus amongst stakeholders on problem definitions, key variables, and even possible solutions. As such, cost-benefit analysis can be more than just a method for informing decision makers; it can also be a means for structuring stakeholder interaction.

6.3 Current practice: comparing CBAs

This section discusses the use of cost-benefit analysis in the field of Health, Safety and the Environment (HSE). It was inspired by work carried out at the Environmental Impact Assessment Agency (MNP) in which the outcomes of numerous cost-benefit studies had to be compared. But how comparable are results from different cost-benefit studies in the field of HSE in the Netherlands? This section discusses the comparability of a relatively small number of cost-benefit analyses. Although it would clearly be inappropriate to claim comprehensiveness, the selected CBAs cover a range that is

[43] Source: interviews with government officials and industry representatives.

sufficiently broad to illustrate the main point of interest here: that a comparison of the outcomes of different CBAs can be deeply troublesome. This is most unfortunate when politicians want to use CBAs to prioritize investments across policy domains.

The five selected cost-benefit analyses are listed in Table 6. All are concerned with health and safety: the control of Campylobacter (the infamous bacteria in chicken meat), the discouragement of tobacco smoking, soil remediation, and accident prevention in the domains of external safety and road safety. Table 6 shows which health metrics and discount rates were used in these cost-benefit analyses. The table also shows whether health impacts were monetized and how the outcomes were finally presented to decision makers. This selection of variables is obviously limited. We could for instance also consider the methods that were used for the monetization of loss of life, or the cost components that were taken into account in some studies but not in other (e.g. loss of worker productivity). The objective of this section is however merely to raise awareness for the fact that there might be considerable differences between the assumptions that underlie the outcomes of cost-benefit analyses in the field of health, safety and the environment.

As shown in Table 6, different health metrics were used in these different studies: DALYs (disability adjusted life years) with and without discounting, QALYs (quality adjusted life years), fatalities, and hospitalized persons. Intangibles were not always monetized and included in the financial balance: while intangibles were listed separately in the chain studies chlorine, ammonia and LPG, a single financial balance was presented for soil remediation operations. Such monetary valuations can have a considerable impact on the net present value of gains and losses. Monetized health impacts for instance dominated the present value of the gains from soil remediation operations.

Most cost-benefit analyses assumed a discount rate of 4%, the then prescribed risk-free discount rate for government projects in the Netherlands. Although the discount rate can strongly influence the present value of future costs and benefits, the sensitivity of the ranking of alternatives to the discount rate was not always analyzed. For instance, the study about the costs and gains of measures to improve the safety of lorries and haulage companies only showed results for a discount rate of 4%.

Unlike the other cost-benefit studies, the study about the cost-effectiveness of interventions to reduce tobacco smoking in the Netherlands assumed the perspective of the government (the department of public health) by considering medical expenditures only. But a government that optimizes its balance sheet need not act on behalf of its citizens: a strong increase in taxation to boost government income could for instance do serious harm to the economy.

The comparison of the five cost-benefit analyses shows that decision makers should be aware that different CBAs need not be based on similar assumptions. While cost-benefit analyses that are tailored to a specific problem can be wholly useful for comparing alternative solutions, lack of uniformity across cost-benefit analyses can severely hamper a cross-sectoral comparison of reported financial balances.

Table 6
A selection of cost-benefit studies for HSE-policies in the Netherlands

Case	Health metric (yr^{-1})	Presentation of outcomes	Discount rate (yr^{-1})
Chain studies Chlorine, Ammonia, LPG (KPMG et al., 2004)	Expected number of fatalities Expected number of injuries Probability of more than 10 fatalities	Net present value of costs and gains, together with a balance of intangibles	7%, sensitivity analysis with 4%
Cost-benefit analysis of measures for lorries and haulage companies (Langeveld and Schoon, 2004)	Deaths, hospitalized persons Fatalities monetized at 7.1mln euro per fatality. This figure corresponds to the total social costs of traffic accidents (incl. 'immaterial loss') divided by the number of victims.	Three presentations: Ratio of costs to deaths+wounded Benefit-cost ratio Net present value of costs and gains	4%
Cost-effectiveness of interventions to reduce tobacco smoking (Feenstra et al., 2005)	QALY[b]	Costs per averted QALY	4% plus sensitivity analysis
Costs and benefits of controlling Campylobacter (Havelaar et al., 2005)	DALY[a] with discounting at 4%	Costs per averted DALY	4%
Societal cost-benefit analysis for soil remediation operations (Van Wezel et al., 2006)	DALY (not discounted), IQ-loss, cancers DALYs monetized at 70.000, 20.000 and 10.000 euros per life year lost. IQ-loss monetized at 10.000 euros per IQ-point	Net present value of costs and gains (NPV)	1%, 2%, 3%, 4%, 7%

a DALY stands for Disability Adjusted Life Year. The value of future life years can be discounted (as in the Campylobacter study).
b QALY stands for Quality Adjusted Life Year (≠DALY)

6.4 Conclusions

1. Although cost-benefit analysis can be useful for organizing disparate information in a consistent manner (see also Arrow et al., 1996), the outcomes of cost-benefit analyses rest on various value-laden choices such as the choice for a social discount rate and a risk metric. When stakeholders cannot agree on these matters, it is unlikely that cost-benefit analysis will be of much use to support decision making.

2. Different methods have been developed for the monetization of non-market goods. When stakeholders disagree on valuation methods or valuations, it seems preferable to present the results of sensitivity tests, or to list the balance of intangibles apart, quantified where possible. This balance of intangibles can then be weighed politically against the net financial balance.

3. When estimating intangible losses, it should be kept in mind that substitution can give rise to an important ripple effect. People that stop driving a car might for instance get into cycling accidents. Arbitrary cut-off might be needed to estimate "net" health impacts. For market goods, this problem is often less severe: when secondary markets operate efficiently, we can limit ourselves to the effects of policies on primary markets.

4. Decision makers should be aware that cost-benefit analysis in the field of health, safety, and the environment lack a strong common basis. It can therefore be troublesome to compare reported financial balances. Changes in loss of life are for instance not always valued in money terms and included in the financial balance. Given such differences, decision makers should be careful to prioritize actions across policy domains on the basis of reported financial balances alone.

Chapter 7

Societal risk criteria

This chapter deals with criteria that are widely used for the evaluation of societal risks: FN-criteria. How do these criteria relate to expected utility theory?

7.1 Introduction

Societal risk criteria can be used to evaluate the probabilities or frequencies of (large-scale) accidents. These criteria come in wide variety of forms, such as risk integrals and FN-criteria (see Jonkman et al., 2003 for an overview). For illustrating the possibilities and limitations of societal risk criteria in regulatory contexts, the remainder of this chapter focuses on a common type of societal risk criteria: FN-criteria. These criteria are widely used to evaluate risks to the public, both in the field of the production, storage, and transport of hazardous materials (see Ball and Floyd, 1998), as well as the field of mass transit (see Dodman and Ransley, 1995; Geyer et al., 1995; Leighton et al., 1995).

An FN-criterion is defined by three variables: (i) its base point (the exceedance frequency of 1 fatality), (ii) its slope, and (iii) its frequency and/or consequence cut-off. Figure 13 shows the different constraints that together make up an FN-criterion.[44] The FN-criteria that are used in the Dutch major hazards policy lack frequency and consequence cut-offs. FN-criteria typically have slopes between between -1 and -2 (Ball and Floyd, 1998). A horizontal FN-criterion would limit the cumulative frequency of accidents, regardless of accident size. A vertical FN-criterion would limit accident size, regardless of accident frequency. Slopes smaller than -1 reflect aversion to larger accidents. To substantiate such aversion, one could argue that larger accidents increasingly affect the ability of a community to function, both socially and economically (e.g. Stallen et al., 1996). Empirical work also shows that decision makers typically place greater weight on larger accidents (e.g. Hubert et al., 1991). Behavioural decision

[44] An FN-criterion could be given different slopes for different fatality numbers. There could also be an ALARP or ALARA-zone to smooth the transition from the acceptable to the unacceptable region.

theorists have however criticized the oversimplified nature of risk criteria that model the social costs of accidents by a function of the number of fatalities (Slovic et al., 1984).

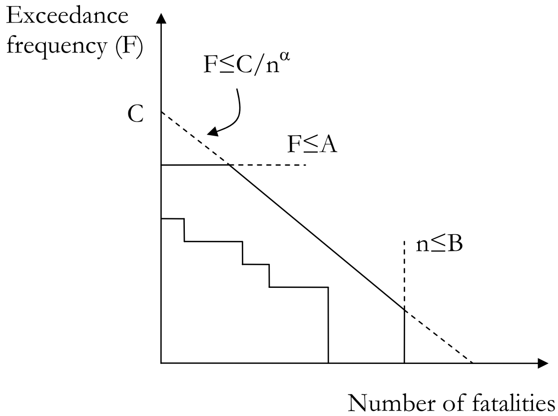

Figure 13 A fictitious FN-curve and an FN-criterion

A criticism of the use of FN-criteria in regulatory contexts is that uniform criteria are typically applied to establishments of different character and size (see also chapter five). Evans and Verlander (1997) showed that uniform FN-criteria can lead to inconsistent tolerability judgments: a redistribution of activities (risks) between two airline companies could influence acceptability judgements. Similarly, splitting up larger establishments into smaller legal entities might influence acceptability judgments when uniform FN-criteria are imposed on individual establishments (Stallen et al., 1996).[45]

The chapter is organized as follows. The first section examines the link between expected utility theory and FN-criteria. The next section discusses methods that rely on the revealed preference hypothesis to derive societal risk criteria.

7.2 Societal risk criteria and expected utility theory

7.2.1 FN-criteria and expected utility theory

FN-criteria are aimed at balancing the (external) social cost associated with large-scale accidents against the costs of risk reduction (see also chapter three). These criteria are however difficult to unite with expected utility theory. Consider for instance a hazardous establishment that could cause n_1 fatalities with probability p_1, and n_2 fatalities with probability p_2 ($n_1<n_2$; $p_1>p_2$). A decision maker is asked to evaluate risk acceptability. Let

[45] The individual risk criterion initially ensured that splitting up larger plants into smaller entities would not be a means to resolve an exceedance of the societal risk criterion. Individual risk would almost certainly be an issue for the new neighbouring entities, forcing one of them to close down (consider for instance the case of Eurometaal). This neighbouring plant provision was however abandoned with the introduction of the External Safety Decree (Bevi) in 2004.

us assume that the decision maker's disutility function U^- is a function of the number of fatalities[46] and that the decision maker is risk averse (Figure 14).

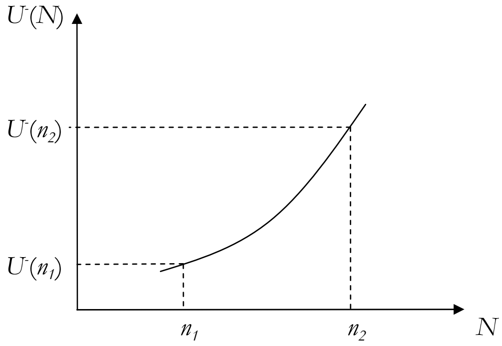

Figure 14 The decision maker's disutility function

Expected disutility equals $p_1U^-(n_1)+p_2U^-(n_2)$.[47] When the decision maker considers the risk just acceptable, he or she could define the FN-criterion shown in Figure 15. Any increase in p_1 or p_2 (or n_1, n_2) would cause expected disutility to increase, leading the decision maker to object to the hazardous establishment.

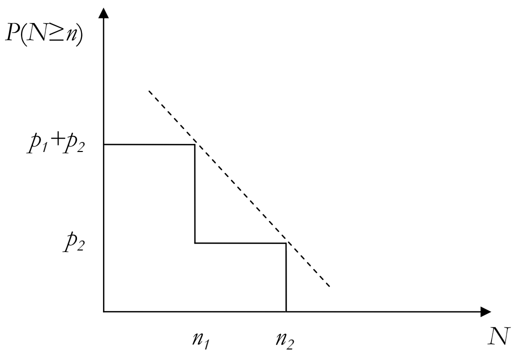

Figure 15 An FN-curve and an FN-criterion that corresponds to the decision maker's judgment

[46] Societal risk criteria typically consider loss of life. A notable exception is the Swiss societal risk criterion that considers consequence classes: fatalities, injuries, m^3 or km^2 polluted surface water, duration of ground water pollution, soil pollution ($km^2 \cdot yr$), and damage to property (10^6 Fr).

[47] For reasons of simplicity, it is assumed that accidents are mutually exclusive (no cross-terms). The differences between probabilities and frequencies are ignored here. It could be argued that the cumulative frequencies shown in FN-diagrams for hazardous establishments should, in fact, be interpreted as cumulative probabilities. This assumption will be relaxed in section 7.2.2.

Now let us assume that the second accident scenario with the n_2 fatalities could be altogether avoided (p_2=0). This would probably affect the probability of an accident with n_1 fatalities that the decision maker would just consider acceptable. The previously defined FN-criterion would only still be appropriate when its value of $P(N \geq n_1)$ would still be the same, which presupposes:

$$p_1 U^-(n_1) + p_2 U^-(n_2) = (p_1 + p_2) U^-(n_1) \qquad (U^-(n_1) > 0) \tag{7.1}$$

Or:

$$U^-(n_2) = U^-(n_1) \tag{7.2}$$

Hence, the same FN-criterion would only still be appropriate if the decision maker were to value n_1 fatalities similarly as n_2 fatalities. Every fatal accident would then be considered equally regrettable, irrespective of accident size, which hardly seems realistic. When the decision maker is risk neutral or risk-averse, an accident with n_2 fatalities would be considered worse than an accident with n_1 fatalities: $U^-(n_2)>U^-(n_1)$. Without the probability of an accident with n_2 fatalities (p_2=0), the decision maker would allow higher values of p_1 and/or n_1. Numerical examples are shown in Figure 16. The figure shows a two-scenario- FN-curve (with n_1=10; p_1=10^{-2}; n_1=100; p_2=10^{-4}), and four single-scenario-FN-curves that would be considered just as unpleasant by decision makers with disutility functions $U^-(n)=\gamma n$ (γ>0), $U^-(n)=n^2$, $U^-(n)=e^{0.01n}$, and $U^-(n)=e^{0.1n}$ respectively.

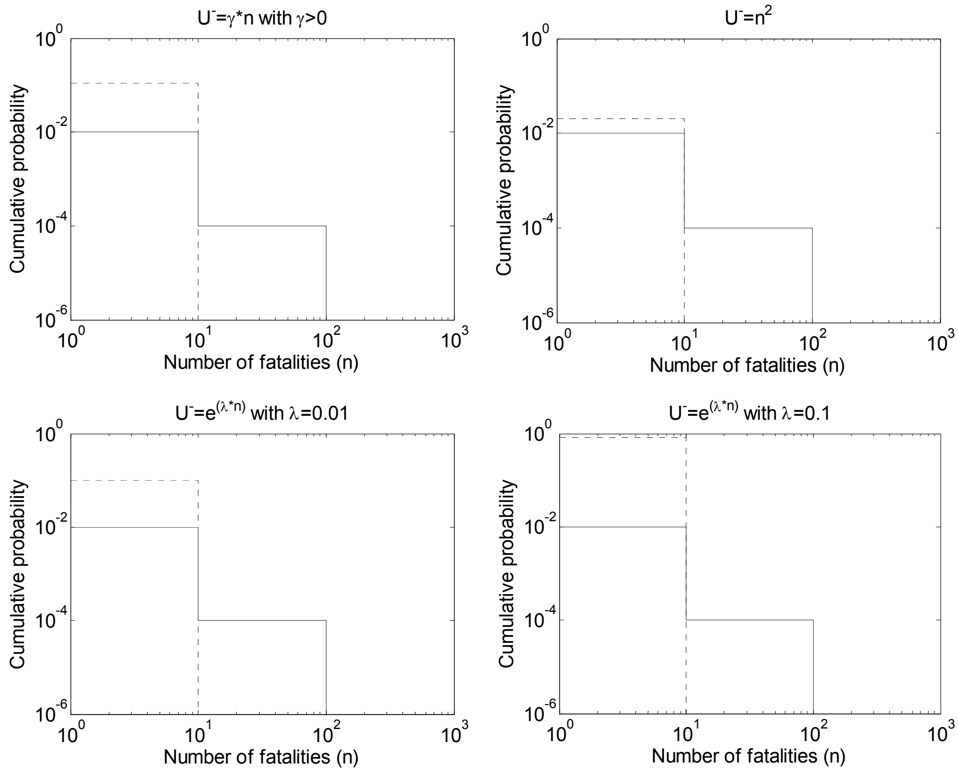

Figure 16 FN-curves that would be considered just as bad for different utility functions

With the appropriateness of an FN-criterion depending on the FN-curve that is to be evaluated (unless $\mathrm{d}U(n)/\mathrm{d}n=0$), it becomes problematic to set FN-criteria in a manner consistent with expected utility theory.

7.2.2 A multi-attribute approach

Various measures have been proposed in literature that would allow us to compare different FN-curves in a consistent manner (see e.g. Vrijling and Van Gelder (1997) and Jonkman et al. (2003) for an overview). A common measure is the weighted risk integral:

$$RI = \int_{0}^{\infty} n^{\alpha} f_n dn \tag{7.3}$$

Where RI = risk integral; n = number of fatalities in an accident; a = coefficient; f_n = frequency of n fatality accidents (per year).

For a =1, the risk integral equals the expected value of the number of fatalities. The risk integral is often interpreted as an expected disutility, with n^a being the utility function, and a indicating the degree of risk aversion (e.g. Hirst, 1998). The interpretation of the

Risk Integral as a utility function would however only be correct when frequencies should in fact be interpreted as probabilities (as assumed in the previous section). Also, it would only be correct when the number of deaths is considered to be a sufficiently comprehensive quantity for expressing the pain caused by accidents. Instead, one might argue that 5-fatality accidents are very different from 10-fatality accidents, not just because the number of fatalities is greater. Accidents with different numbers of fatalities should then be treated as different attributes.

The multi-attribute approach set out by Bedford (2005) recognizes the differences between probabilities and frequencies. It also recognizes the differences between accidents of different sizes by defining consequences as the number of n-fatality accidents, rather than the number of fatalities. Under a multi-attribute approach, separate disutility functions should be defined for the numbers of n-fatality accidents. Assuming the absence of interactions between the preferences over the random attributes, we could assume a disutility function of the form (Chavas, 2004; Keeney, 1992):

$$U^{-}(m_1, m_2, m_3, ...) = \sum_n k_n U_n^{-}(m_n) \tag{7.4}$$

Where $U^{-}_n(m_n)$ = disutility function for the number of accidents (m_n) with n fatalities; k_n = weight.

Assuming that the number of occurrences of n-fatality accidents in a year can be described by a Poisson process, the probability of exactly m_n events per annum equals:

$$p(m_n) = \frac{e^{-f_n} \cdot f_n^{m_n}}{m_n!} \tag{7.5}$$

Where $p(m_n)$ = probability of exactly m events with n fatalities in a year; f_n = annual frequency of events with n fatalities. Expected disutility could then be written as:

$$EU^{-}(m_1, m_2, m_3, ...) = \sum_n \sum_{m_n} \frac{e^{-f_n} \cdot f_n^{m_n}}{m_n!} k_n U_n^{-}(m_n) \tag{7.6}$$

For events that hardly ever occur f_n<<1, $p(m_n=1) \approx f_n$ and $p(m_n>1) \approx 0$ (all n). If $p(m_n)U^{-}(m_n) \approx 0$ for $m_n>1$ (all n), expected utility converges to:

$$EU^{-}(m_1, m_2, m_3, ...) \approx \sum_n f_n k_n U_n^{-}(1) \tag{7.7}$$

Where $k_n U^{-}_n(1)$ reflects the (relative) disutility of the occurrence of an accident with n fatalities in a year. When the values of $k_n U^{-}_n(1)$ depend only on the number of fatalities (for all n), expected disutility would once again depend only on accident frequencies and fatalities. Say $k_n U^{-}_n(1) = n^{\alpha}$, we would obtain:

$$EU^{-}(m_1, m_2, m_3, ...) \approx \sum_n f_n n^{\alpha} \tag{7.8}$$

The above expression looks similar to the risk integral (equation 7.3). Yet the derivation shows that *a* indicates the degree to which people are averse to larger accidents, but that it should not be interpreted as a risk aversion coefficient in an expected utility sense (Bedford, 2005).

7.2.3 A practical interpretation of FN-criteria

The previous sections showed that FN-criteria are difficult to unite with expected utility theory, even for highly simplified cases. The simplifying assumptions that were made need not always be realistic. It for instance seems likely that a decision maker's appraisal of the frequency of ten-fatality accidents will be influenced by the number of accidents with less than ten fatalities (see also Bedford, 2005), thus violating utility independence. The analysis is further complicated by the problem of collective choice (see also section 1.4.3). While a theoretical link between expected utility theory and FN-criteria might be hard, if not impossible, to establish, FN-criteria could still be practical instruments to (roughly) balance risks against other interests. A too stringent criterion would be unduly costly, but a too lenient criterion would allow the too frequent occurrence of large-scale accidents.

7.3 Societal risk criteria and the revealed preference hypothesis

Balancing risks against other interests is by no means straightforward. The use of cost-benefit analysis to derive societal risk criteria might seem to most closely fit the ethic on which this thesis rests. But cost-benefit analysis can be time-consuming and costly. Moreover, estimating and valuing the impact of large-scale accidents on social life can be hugely complicated. An alternative method would be to assume that accident statistics reflect the outcome of a long process of trial and error, thereby revealing a reasonably optimal balance between safety and other interests. This so called revealed preference hypothesis basically holds that "is" equals "ought". Although the hypothesis is controversial, it can be useful for identifying outliers and stimulating debate (see also Bohnenblust and Slovic, 1998; Vrijling et al., 1998).

An attempt to link mortality estimates to hazard characteristics was first made in a seminal article by Starr (1969). Using such a link, we would be able to say whether an activity would be unusually risky compared to other activities with similar characteristics. Vrijling et al. (1995) proposed a model, based on accident statistics, for deriving societal risk criteria for activities with different degrees of voluntariness and direct benefits. The model comprises a variable named policy factor to make ends meet (Figure 17). This factor could be interpreted as a compound indicator for the psychological and contextual factors that influence risk acceptability. Although it would obviously be a gross simplification of reality to assume that the complexities of social life can enter a model through a single variable, the main purpose of the policy factor is to put risks into perspective. And when it comes to the choice for risk criteria that can be used for engineering purposes, scientific rigour inevitably has to be sacrificed for practicality. The societal risk criterion proposed by Vrijling et al. (1995) reads:

$$E(N_i) + k \cdot \sigma_i < \beta_i \cdot 100 \tag{7.9}$$

Where $E(N_i)$ = expected number of fatalities caused by activity i per year; k = constant; σ_i = standard deviation of the number of fatalities per year; β_i = policy factor

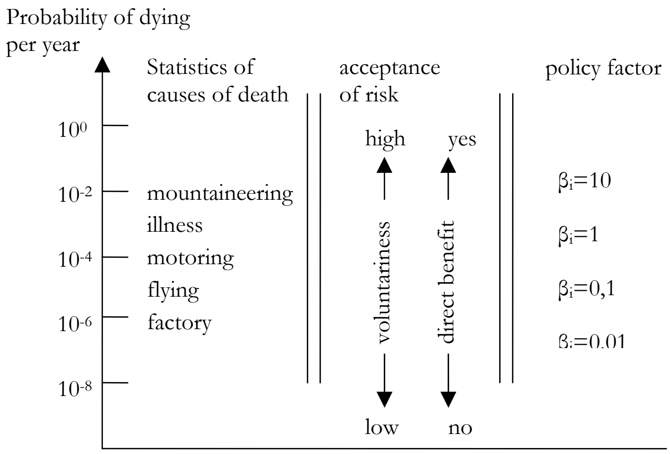

Figure 17 Values of the policy factor (Vrijling, 2001)

Although it seems reasonable to assume that voluntariness is proportional to risk acceptance, risk acceptance might also be inversely related to voluntariness. Consider for example a poor man that has no other option than taking an old and unsafe car to work. One could argue that the voluntariness of driving the car is low: the man simply has no other options. Yet lack of substitutes positively influences his attitude towards the car. As the example demonstrates, it would seem preferable to define the policy factor in terms of opportunity cost. The availability of substitutes, the costs of risk reduction, and the benefits brought about by normal operation are then the variables that define the policy factor. These variables will often be positively correlated with voluntariness, but that will not always be the case.

7.4 Societal risk criteria at national and local levels

The societal risk criterion proposed by Vrijling et al. (1998) is based on the idea that societal risk should primarily be evaluated at a national level as local developments may lead to a situation that is considered unacceptable by society as a whole. The next step would be to distribute this societal risk budget over individual establishments. The distribution of a national risk budget over individual hazards should ideally be based on the marginal cost of risk reduction in each particular case. This, however, seems unduly complicated. Perhaps the amount of hazardous material processed by an establishment could serve as a reasonable proxy. But not all hazardous materials are equally hazardous. As a remedy one could normalize the amount of each substance by the threshold value mentioned in the Annex of the Seveso II Directive. The relative size (ψ_i; $\sum\psi_i$=1) of a hazard *i* is then be defined as:

$$\psi_i = \frac{Q_i}{\sum_{i=1}^{n} Q_i} \quad \text{with} \quad Q_i = \sum_{\eta=1}^{m} \frac{q_{\eta i}}{T_\eta} \tag{7.10}$$

Where Q_i = normalized quantity of hazardous material at establishment *i* (/yr); $q_{\eta i}$ = quantity of hazardous material η at establishment *i* (tonnes/yr); T_η = threshold of the quantity of hazardous material η mentioned in the Annex of the Seveso II Directive (tonnes).

Although this method can hardly be called scientifically sound, its main purpose is to stimulate debate on ways to improve the proportionality of societal risk criteria. Uniform societal risk criteria imply similar weights for all individual hazards. Such uniform weights would only be reasonable if all establishments or transport kilometres were to be broadly similar.

7.5 Case study: the transport of hazardous materials

Population densities vary considerably along transport routes and it seems unlikely that the costs of risk reduction will be the same for all kilometres (Figure 18). Yet the current FN-criterion for the transport of hazardous materials ($10^{-2}/N^2$ per km per yr) is the same regardless of the kilometre under consideration.

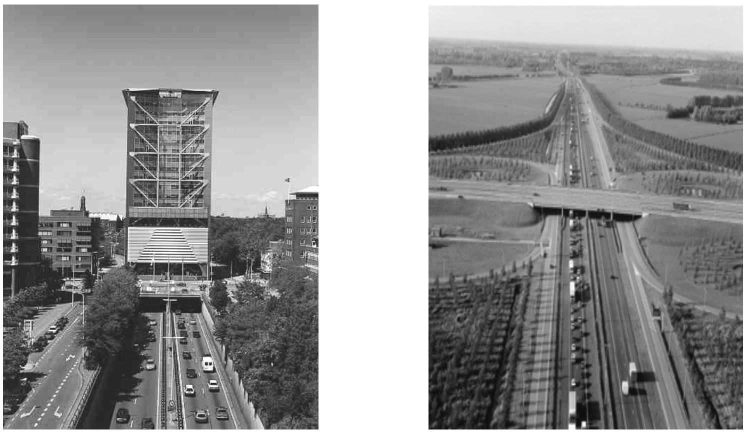

Figure 18 The physical surrounding of transport routes varies considerably throughout the country

The use of an FN-criterion that is defined per kilometre may well lead to different acceptability judgments than a criterion that is defined per say 10, 25 or 50 kilometres. Consider for instance the FN-curves for two transport routes of 25 kilometres. Which case would be preferable: case I in which all 25 kilometres just meet the FN-criterion for the transport of hazardous materials; or case II in which the FN-criterion per kilometre is exceeded by a factor 5 for one kilometre while the level of societal risk is low for all other kilometres (Figure 19)? An evaluation of societal risk per kilometre would lead to a positive acceptability judgment for case I and a negative one for case II. But the aggregate FN-curve is lower in case II than it is in case I. Case II would thus be preferable from a national perspective, while the use of an FN-criterion that is defined per kilometre would lead to the opposite judgment.

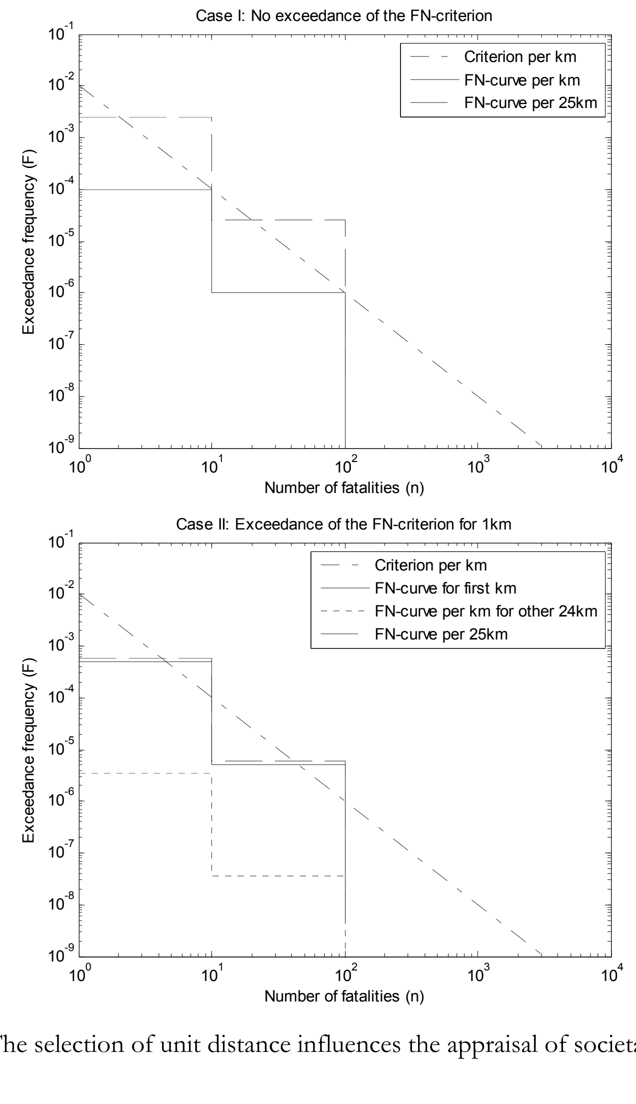

Figure 19 The selection of unit distance influences the appraisal of societal risk

How could the revealed preference hypothesis be used for defining FN-criteria that would do greater justice to the differences between transport kilometres? The following procedure could be used:

1. Define a national FN-criterion on the basis of risk estimates or accident statistics.
2. Distribute the national societal risk budget over individual transport routes on the basis of marginal cost.

Step 1 Define a national FN-criterion

Should an FN-criterion be defined for the transport of all hazardous materials by all transport modes? Or perhaps for the transport of a specific substance by a specific transport mode? The alternatives are listed in Table 7.[48]

Table 7

Deciding on the scope of a societal risk criterion for the transport of dangerous goods

	Per hazardous material	**All hazardous materials**
Per transport mode	**1 material, 1 mode** e.g. the transport of LPG by road	**all materials, 1 mode** e.g. the transport of LPG, chlorine etc. by railroad
All transport modes	**1 material, all modes** e.g. the transport of LPG by road, train, ship and pipeline	**all materials, all modes** the transport of LPG, chlorine etc. by road, railroad, ship and pipeline

It is assumed here that societal concerns are most strongly related to the transport of all hazardous materials by a single transport mode.[49] The remainder of this section focuses on the transport of hazardous materials by road. Figure 20 shows an FN-criterion with slope -2 that is tangent to the FN-curve for the transport of hazardous materials by road in the Netherlands ($1.5/n^2$ per year).

[48] Societal risk could also be calculated for a region (housing all sorts of activities) rather than an activity. Such spatial societal risk is however difficult to relate to risk perceptions: psychometric studies typically relate risk perceptions to hazards and their characteristics, rather than to aggregate risks (from a variety of sources) in specific regions.

[49] This has the concomitant advantage that there will only be one societal risk criterion that has to be evaluated for spatial plans (no separate criteria for different substances).

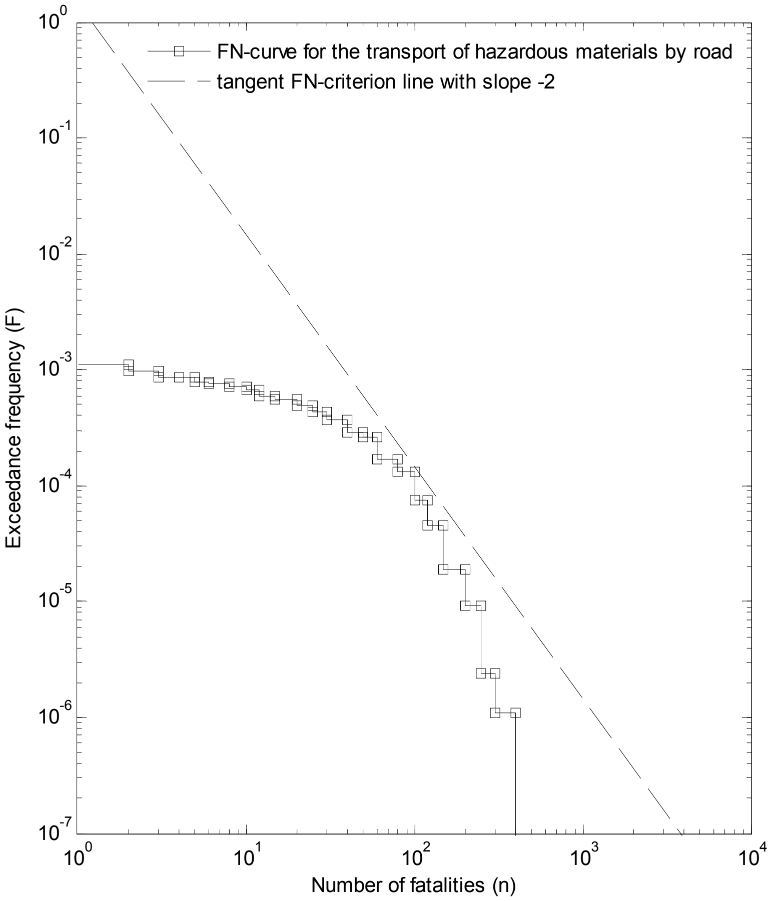

Figure 20 National FN-curve for the transport of hazardous materials by road and a tangent FN-criterion (data from RIVM, 2001)

Step 2 Distribute the national societal risk budget over transport routes

The present FN-criterion for transport activities is defined per kilometre per year. But we could also calculate FN-curves for transport *routes* (e.g. Cassini, 1998) and introduce FN-criteria for transport routes rather than a single, uniform criterion for all transport kilometres. On the basis of equation (7.10), societal risk budgets should be allocated on the basis of each route's contribution to the transport of (normalized quantities of) dangerous goods throughout the Netherlands. To illustrate the workings of this procedure, consider a fictitious road network (Figure 21) along which fictitious amounts of hazardous materials are transported (Table 8). For reasons of simplicity, let us assume that only Liquefied Petroleum Gas (LPG) and chlorine are transported in substantial quantities.

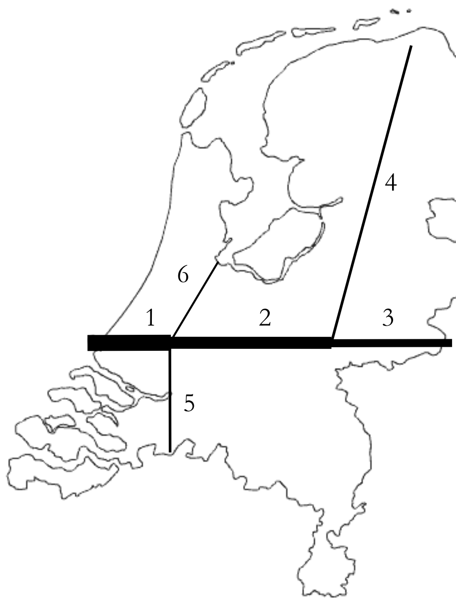

Figure 21 Fictitious transport routes for the transport of hazardous materials by road

Table 8
Fictitious quantities of hazardous materials transported by road along each route (thresholds according to Annex II of the Seveso Directive)

Route	LPG (ktonnes/year) Threshold: 200t	Chlorine (ktonnes/yr) Threshold: 25t	Normalized quantity (/yr)	Relative size of route (ψ_i)
1	250	5	1450	0.36
2	190	5	1150	0.28
3	170	0	850	0.21
4	15	5	275	0.07
5	40	0	200	0.05
6	30	0	150	0.04

Using equation 7.10, each route would be allocated a fraction ψ_i of the national societal risk budget. The FN-criterion for route 1 would for instance be $(0.36*1.5/n^2=)$ $0.54/n^2$ per year. The resulting FN-criteria for all six transport routes are shown in Figure 22.

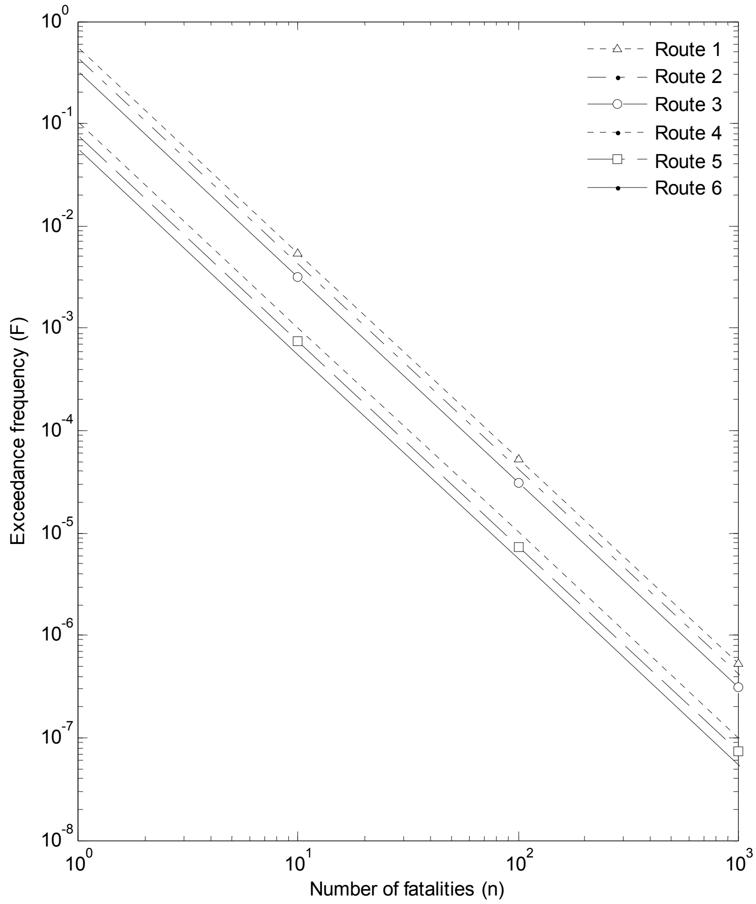

Figure 22 FN-criteria per transport route

The proposed methodology could perhaps be used to flesh out a corridor approach. It seems that roughly two corridor classes could be discerned in this fictitious transport network: one class with an FN-criterion *per route* of about $3.10^{-1}/n^2$ and one with an FN-criterion *per route* of about $5.10^{-2}/n^2$. For reasons of practicality, one could go one step further and use these two criteria to define FN-criteria *per kilometre* per route. For evaluating the acceptability of societal risks, analysts would then only have to estimate the FN-curve for a specific kilometre rather than an entire transport route.[50]

[50] FN-curves and FN-criteria are only part of the decision making process to control risks to the public.

7.6 Conclusions

1. Societal risk criteria, such as FN-criteria, can be useful for balancing the probabilities and severities of large-scale accidents against the costs of risk mitigation. A formal link between FN-criteria and expected utility theory has however not yet been established, and it seems unlikely that this can be easily achieved.

2. Various scholars have proposed revealed preference models that link hazard characteristics and risk estimates or accident statistics to societal risk criteria. Although such models can be useful for putting risks into perspective, the trade-off between practicality and scientific rigour is often considerable.

3. Uniformly distributing societal risk budgets over individual establishments or transport corridors is to confuse efficiency and equity. Based on the premise that societal risk should be evaluated primarily at a national level, societal risk budgets should be allocated on the basis of the marginal costs of risk reduction in each particular case. When these differ from case to case, societal risk criteria should differ accordingly. Since the marginal cost of risk reduction in each particular case may be difficult (costly) to estimate, a simplified procedure has been proposed that is based on a plant's (or transport route's) contribution to total production or transport. The proposal obviously lacks scientific rigour but it could perhaps stimulate debate about ways to improve the proportionality of societal risk criteria. And that, above all, is its main purpose.

Chapter 8

The precautionary principle

From the viewpoint of welfare economics, risk regulation is essentially a balancing act. Would "the" precautionary principle be a suitable principle for risk decision making from that perspective?

8.1 Introduction

No thesis on risk regulation would seem complete without mention of the much debated precautionary principle. It is the subject of great controversy and it has strong supporters as well as strong opponents. Fierce debate concerns the questions whether the principle hampers socio-economic development (e.g. Beachy, 1999; Holm and Harris, 1999), whether it is used as a guise for protectionism (e.g. Schomberg, 2004; Scott et al., 1999; Van den Belt, 2003), and whether it could serve as a rational basis for decision making (e.g. Peterson, 2006). While the principle is most commonly referred to in debates about new technologies that (could) entail new risks, it is also frequently mentioned by policymakers and politicians in debates about conventional risks, such as flood risks.

Despite its widespread use, "the" precautionary principle lacks a single definition (Foster et al., 2000). Scholars have proposed various definitions of the principle that would make it consistent with economic theories about decision making under uncertainty (e.g. Barrieu and Sinclair-Desgagné, 2006; Gollier and Treich, 2003). Other scholars have concerned themselves with (the consequences of) the ways in which the principle is actually implemented (e.g. Majone, 2002). This chapter fits the latter stream: it describes the various interpretations of "the" precautionary principle and evaluates two recurrent themes from a utilitarian perspective.

Having surveyed the literature on "the" precautionary principle, I suspect that much debate over its merits stems from different interpretations of probability. Scholars frequently posit that "the" precautionary principle should be invoked in situations in which probabilities are said to be highly uncertain, i.e. "highly subjective" rather than "scientifically established". [51] But under a personal interpretation of probability, probabilities are inherently subjective (see also Appendix I). We might be unable to accurately predict whether it will rain when we look out the window. But this does not prevent us from balancing our degree of belief that it will rain miserably against the effort of bringing an umbrella.

A difficulty arises when people have to reach a decision that affects them all. Putting up a marquis to stay dry would require a joint effort. Even if they all value this effort similarly, as well as the misery of getting wet, they could still disagree about the marquis, just because they disagree about the probability of rain. Dispute could thus arise solely because people hold different degrees of belief about the prospect of rain. This introduces the problem of collective choice: how to reconcile the preferences of different individuals? But the problem of collective choice is not exclusively linked to situations in which people disagree about probabilities: they could also value consequences differently. Some people might actually enjoy a little rain.

It would make a discussion of "the" precautionary principle needlessly complex by combining it with a discussion of the normative dilemmas that surround collective choice. This text therefore focuses on situations in which every individual holds identical beliefs and preferences. While this might sound unambitious, a test of "the" precautionary principle within such a context (which is effectively a single decision maker context) could be interpreted as a minimal test that any guiding principle for risk decision making should be able to pass.

The chapter is organized as follows. As there is no single definition of "the" precautionary principle, the chapter starts off by providing an overview of its different interpretations. The next section discusses two recurring themes in these interpretations: the advice to err on the safe side, and the attempt to link risk characteristics to some type of regulatory action.

8.2 Interpretations of the precautionary principle

Despite lack of a single, clear definition, "the" precautionary principle has been mentioned in numerous international treaties and declarations: the Ministerial Declaration of the Second and Third International Conferences on the Protection of the North Sea (1987 and 1990), the Convention of Biological Diversity (1992) and the Convention of Climate Change (1992). An often cited description of "the" precautionary principle is the one provided by the 1992 Rio Conference on the Environment and Development: "In order to protect the environment, the precautionary approach shall be widely applied by States according to their capability. Where there are threats of serious or irreversible damage, lack of scientific certainty shall not be used as reason for postponing cost-effective measures to prevent environmental degradation" (UNCED, 1993).

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[51] Bedford and Cooke (2001: 35) criticize of the use of the terminology "uncertainties over probabilities", arguing that it "encourages sloppy thinking and misunderstanding". Under a personal interpretation of probability, "uncertainty over probabilities" becomes "uncertainty over uncertainty".

There are numerous other interpretations of "the" precautionary principle (e.g. Sandin, 1999). In its most stringent form, the principle requires absolute proof of lack of harm before a potentially hazardous activity is considered acceptable. While few, if any, scholars seem to adhere to this interpretation, it seems less uncommon in public debates. Since it impossible to be know whether an activity is perfectly safe, the questions that have to be answered are: "how much certainty is needed?" and "how much precaution would be appropriate?" (Bodansky, 1991). If one were to be unwilling to accept any probability of harm, the precautionary principle would be reduced to an absurdity. We would for instance have to decide to move millions of people from the low-lying parts of the Netherlands to higher grounds. And on higher grounds, they might be exposed to other risks.

Under a largely procedural interpretation, the principle stands for a dynamic process of risk appraisal in which risk mitigation policies are constantly being reviewed in the light of scientific progress and forthcoming information. Such a process would be wholly consistent with an evidence-based or "traditional" risk management approach (Stirling, 1999; 2001), while allowing for multiple perspectives and public scrutiny (e.g. Munnichs, 2004). A reversal of the burden of proof is also a key element in most procedural interpretations of the precautionary principle (e.g. Tickner, 1999). REACH, the EU regulatory framework for the Registration, Evaluation and Authorization of Chemicals (2003) obliges the industry to demonstrate that new chemicals are sufficiently safe before they can be introduced. Such precautionary provisions can arguably also be found in the Dutch major hazards policy: a hazardous establishment has to demonstrate it is sufficiently safe before it is granted a permit and allowed to operate (Ale, 2005; Jongejan et al., 2006).

The European Commission has recently issued a communication stating its position on the precautionary principle (EC, 2000). The EC's version of the principle is strongly process-oriented as it sets quality criteria for the risk management process. Scientific evidence plays an important role: a decision to trigger the precautionary principle should be based on "a scientific evaluation, as complete as possible, and where possible, identifying at each stage the degree of scientific uncertainty" (EC 2000: 17). Precautionary measures should be maintained as long as scientific evidence is "inadequate, imprecise or inconclusive and as long as the risk is considered to be too high" (EC, 2000: 20). The European Commission lists six general principles that should underlie precautionary policies. They should be (i) proportional, (ii) non-discriminatory, (iii) consistent, (iv) based on an examination of costs and benefits, (v) subject to review and (vi) capable of assigning the burden of proof. The precautionary principle is thus interpreted as a legal principle, a guideline for decisions, rather than a legal rule (Arcuri, 2005). Although the six principles advocated by the European Commission hardly seem controversial (one could argue that they should ideally underlie all government policies), this does not automatically hold for the way "the" principle is actually applied. After all, the EC communication provides no clear guidance for decision making (see also Marchant, 2001; 2003).[52]

[52] It is striking in this respect that the EC's application of "the" (or its) precautionary principle has repeatedly led to concerns over protectionism. The dispute over an EC ban on beef treated with hormones from the United States and Canada is an illustrative case (Majone, 2002). The EC had defended its ban by referring to "the" precautionary principle. The WTO's dispute settlement panel however ruled against the EC.

Criticizing "the" precautionary principle seems a nearly impossible task considering the ambiguity that surrounds its definition. Yet in studies and debates about the precautionary principle, two recurring themes are the advice to err on the safe side and the use of risk characteristics as the sole basis for deciding on government actions.

8.3 Two criticisms of the precautionary principle

8.3.1 A bias towards the safe side

Interpretations of the precautionary principle often include a bias towards a greater level of protection. But acting upon the assumption that an activity is not harmful while it is, and acting upon the assumption that an activity is harmful while it is not *both* come at a cost (Page, 1978). A rational decision maker would balance the two types of error without a bias towards the safe side, i.e. without greater weight placed upon the consequences of false-negatives (under-regulation). Although false-negatives can be costly, it would be incorrect to ignore or marginalize the benefits of (potentially) hazardous activities. That said, a bias towards the safe side can *sometimes* be wholly rational.

As the theory of quasi (or real) options shows, a bias towards avoidance of the irreversible state becomes rational under uncertainty about irreversible outcomes and a prospect for learning (Arrow and Fisher, 1974). Postponing or carefully introducing potentially hazardous activities can be a means to exploit the opportunity to learn. To illustrate the origins of quasi-option value, consider a rational decision maker that is asked to appraise a potentially harmful activity that would produce certain profits worth b. The activity might however cause an irreversible loss q. A-priori, it is highly uncertain whether this loss will occur, and the decision maker subjectively estimates this probability to be p. Denote the decision maker's utility function by U and initial wealth by w. The rational decision maker will support the activity when $(1-p)U(w+b)+pU(w+b-q)>U(w)$.

Now let us assume that the decision maker could also postpone the activity and wait for the results of a study that would show with complete certainty (for reasons of simplicity) whether the activity would be harmful or not. By postponing the activity, the decision maker would have effectively bought the option to abandon the activity. The option only expires worthless when the activity turns out to be safe. But when the activity turns out to be harmful, the decision maker will exercise the option and avoid harm (Figure 23).

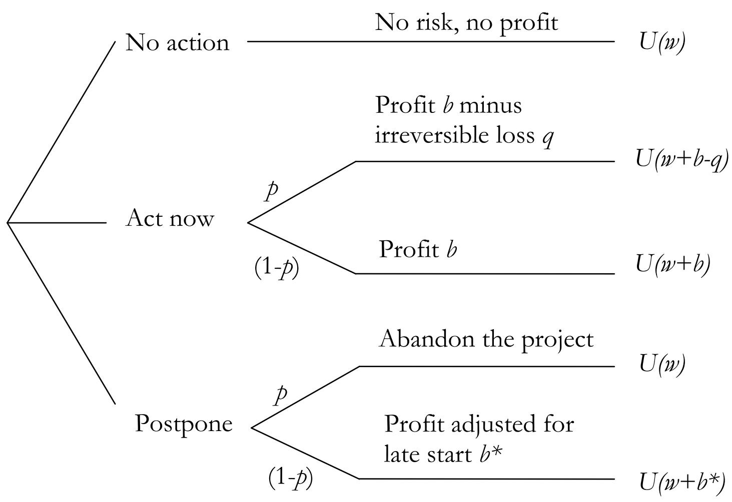

Figure 23 The decision tree: comparing the alternatives

Although it is sometimes stated that the various definitions of the precautionary principle imply risk aversion to various degrees (e.g. Kheifets et al., 2000), the quasi-options framework shows that "erring on the safe side" can be wholly consistent with decision making under risk neutrality (Henry, 1974). This is obviously not to say that risk decisions always *ought* to be risk neutral (although risk neutrality is often assumed on the basis of diversification arguments).

Kheifets et al. (2000) noted that the stringency of regulatory intervention prior to proof of harm is often related to the severity of potential harm and the degree of epistemic uncertainty. Although the prospect for learning was not mentioned explicitly, these conditions can easily be linked to quasi-option value, which can be thought of as the expected value of information (Conrad, 1980). Interestingly, scientific research and periodical review of precautionary measures are at the centre of the EC's interpretation of "the: precautionary principle. "Erring on the safe side" and the EC's precautionary principle might thus in some cases be wholly consistent with a utilitarian appraisal of alternatives.

But unfortunately, not all risk decisions involve an embedded option. When there is no prospect for learning and/or irreversibility, a bias towards the safe side would not be reasonable. It is therefore proposed to assess the value of quasi-options on a case-by-case, rather than to rely on a general decision making principle that recommends a bias that will sometimes, *but not always*, be reasonable.

8.3.2 Risk as the basis for decision making

A second recurring theme in studies and debates about the precautionary principle is the attempt to link risk characteristics to some type of government intervention. Klinke and Renn (2002) for instance developed an extensive risk classification scheme with suggestions for responding to risks belonging to certain classes. Depending mainly on the degree of complexity, controversy and epistemic uncertainty involved, different regulatory approaches were proposed, ranging from legal standards to confidence building. More recently, a modification of Klinke and Renn's classification scheme was presented by Kristensen et al. (2006). Again, risk characteristics were linked to risk management strategies. Although these approaches are intuitively appealing and practical for specific contexts, the premise that the choice for a regulatory approach can based on risk characteristics alone is challenged here.

Risk is often the by-product of an activity that is carried out because it brings gains to some. A focus on risks alone would ignore the gains that a (potentially) hazardous activity or technology could bring about. Risk is only part of the bigger picture. The choice for a regulatory approach should ideally be based on an evaluation of all the pros and cons (of which risk is only one element) of all available alternatives. Put differently, the choice for a regulatory approach should be based on opportunity cost, the value of the best alternative forgone. Some examples will clarify this point.

The probability of a nuclear accident is low but its consequences may well be severe and persistent, and the disposal of nuclear waste poses long-term environmental risks. One might therefore consider it appropriate to invoke "the" precautionary principle and decide not to construct new nuclear power plants. The changing tone of the debate on nuclear power in the US, the United Kingdom and the Netherlands however shows the importance of opportunity cost. Rising prices of fossil fuels and the risk of climate change have raised the (social) costs of traditional sources of power supply. If there were no substitutes for nuclear power generation, a ban on nuclear power plants would give rise to enormous social cost. The appropriate degree of precaution thus cannot be decided on by rules that link risk characteristics to certain types of government intervention. After all, such rules ignore the benefits of the activity under consideration, as well as the (possibly changing) pros and cons of the available alternatives.

Another example concerns the fears that the electromagnetic fields generated by high voltage power lines increase the incidence rate of leukaemia (0.2-1 case per annum (RIVM, 2003)). Under the risk ladder approach proposed by the report "Dealing rationally with risks" (RIVM-MNP, 2003), involvement of the public would be an appropriate strategy. But why should this be an "appropriate" strategy? If land and houses would cost next to nothing, one could simply implement stringent zoning regulations. And if there would be low-cost substitutes for high voltage power lines, why waste effort on consensus seeking discourse?

A final example concerns the EU’s import ban on genetically modified organisms (GMOs). With an abundant supply of crops produced through traditional farming methods, GMOs might be considered not worth the (ambiguous) risk. But if famine were to strike Europe, the European Commission would likely relax its position on the import of genetically engineered crops to relieve the food shortage.

Apart from the expected benefits of potentially hazardous activities, one should also have regard for the costs of government intervention. The administrative costs of implementing policies and enforcing rules can be considerable, and regulations inevitably produce inefficiencies of their own (Coase, 1960). Regulations can even, unintentionally, give rise to new risks. The Netherlands Hazardous Materials (2007) for instance posed that the stringent plant safety regulations that were issued after the Enschede fireworks disaster might have actually reduced public safety by intensifying the transport of fireworks, and by leading to the uncontrolled storage of fireworks in trucks. While a ban on nuclear power generation can easily be enforced by not granting permits for the construction and operation of nuclear power plants, a ban on a potentially hazardous drug might drive it into the illegal circuit, making it hard to exercise control. It seems difficult, if not impossible, to account for the costs of government intervention using general decision making rules that consider risk characteristics alone.

Finally, besides governments, non-sate actors such as the media and advocacy groups can strongly influence the behaviour of individuals or firms (Hutter, 2006). While risk characteristics might call for some type of government intervention (depending on the taxonomy used), the social environment might have already responded in ways that have largely removed the necessity for such intervention. A focus on risk characteristics alone could then easily lead to inappropriate policy recommendations (from a utilitarian perspective).

8.4 Conclusions

1. "The" precautionary principle lacks a single, clear definition. Yet in studies and debates about the precautionary principle, two recurring themes are the advice to err on the safe side and the advice to select risk management strategies on the basis of risk characteristics.

2. The real options framework provides a theoretical justification for a bias towards the safe side *when there is a probability of irreversible harm and a prospect for learning*. Not all risk decisions under uncertainty involve such an embedded however.

3. Considerable work has been done to link risk characteristics to "appropriate" types of government interventions. This seems to ignore the fact that risk is only part of the bigger picture. The expected benefits of an activity should not be overlooked, as well as the costs of government intervention and the way in which non-state actors have already responded to the activity. There should therefore be no place in risk decision making for a bias towards certain types of government action on the basis of risk characteristics alone.

4. It is emphasized that it can sometimes be wholly appropriate to act prior to the establishment of proof of harm. Various scholars have discussed the conditions that would make such intervention consistent with rational decision making under uncertainty (e.g. Arrow and Fisher, 1974; Gollier and Treich, 2003). These conditions could be used to develop definitions of the precautionary principle. But there is a difference between the way some economists would define "the" precautionary principle, and the way it is interpreted by other scientists, politicians, environmentalists, and policymakers. It therefore seems preferable to discuss the conditions that people think should influence decision making in particular contexts, rather than to devote scholarly effort to the definition of an ambiguous principle. Discussing how a decision making principle ought to be defined is effectively a roundabout way of discussing underlying assumptions and value judgments.

PART III

Dealing with losses

Chapter 9

What if..? How prepared is prepared enough?

There is always a probability, however remote, that things go horribly wrong. Should we therefore always be fully prepared for all possible accidents? And if not, how prepared is prepared enough?

9.1 Introduction

Various governments have defined a safety chain to structure their efforts in field of risk management (The Netherlands Ministry of the Interior and Kingdom Relations, 1999a).[53] The chain links the various stages of the risk management cycle. It consists of proaction, prevention, preparation, repression and recovery (Ten Brinke et al., 2008; The Netherlands Ministry of the Interior and Kingdom Relations, 1999b). Proaction concerns risk management at its most basic level: risks can be avoided altogether by simply avoiding hazardous situations. Prevention concerns the mitigation of risks by specifically designing socio-technical systems in a way to ensure safe performance. But the probability of an accident, however remote, will always remain. Preparation involves all activities prior to an accident to improve emergency response. Repression is the actual response to emergencies, and recovery involves all activities in the post-accident phase.

Disaster preparedness falls under the responsibility of the Minister of the Interior and Kingdom Relations (BZK), and it is often evaluated apart from the other links of the safety chain. A report by the Netherlands Hazardous Materials Council (unpubl.) shows that none of the emergency services in the Netherlands would be able to cope with major industrial accidents. Should this be reason for concern? Should disaster preparedness be improved? To answer this question, a more fundamental question has to be answered first: how prepared is prepared enough?

This chapter attempts to address this question at a conceptual level. I am aware that a conceptual treatment of this complex subject does scant justice to the realities of emergency planning. The difficulties in planning responses to low-probability, large-scale

[53] The safety chain is an ambiguous concept that could be interpreted in different ways. It is referred to here because it is widely used by government administrators.

events are well documented (McConnell and Drennan, 2006; Quarantelli, 1988). This, in turn, implies that it will be hard to measure, a-priori, the actual standard of disaster preparedness. Yet the purpose of this chapter is not to be exact but to illuminate basic trade-offs and key variables.

This chapter is organized as follows. The first section introduces a conceptual model that frames and analyses the question "how prepared is prepared enough?" as an economic decision problem. The second section then explores the relations between the various links of the safety chain. It will be shown that these links should not be treated in isolation. Although it is undoubtedly simpler to manage smaller parts than a greater whole, it would be erroneous to assume that optimizations of individual links bring about an optimization of the entire chain. The chapter ends by providing an overview and discussion of the main results.

9.2 Balancing the social costs and gains of disaster preparedness

9.2.1 The balancing act

The popular "what if?" question calls attention to the fact that preparedness for disasters is generally low. The costs of organizational readiness can be considerable, and various scholars have linked budget constraints to poor crisis plans (Boin and McConnell, 2007). The remainder of this section formalizes the link between the costs and benefits of disaster preparedness.

The demands that emergency response organizations are faced with are likely to be relatively stable over time because of the sheer number of independent risks.[54] The total number of individuals that end up in hospital is therefore likely to be fairly constant. But the total number of people that need assistance can be subject to considerable fluctuations when individual exposures and/or vulnerabilities are positively correlated. In winter for instance, many people will simultaneously be more susceptible to catch a cold. And bus accidents affect a number of people at the same time. Extreme demands for assistance are likely to be the result of common cause failures such as epidemics or large-scale accidents. Ever extreme demands become ever less likely. So for what demands should we still be prepared?

A formal model will be now introduced to address this question at a conceptual level. It is severely limited in accuracy but its main purpose is not to be exact but to illuminate the most basic trade-offs involved. The model concerns a hospital that has to optimize its capacity (the model's basic logic applies equally to other emergency services). The model rests on the following two assumptions:

1. *Constant marginal gains*. The effectiveness of a doctor to save patients is independent of the number of doctors employed.
2. *Constant marginal costs*. The costs per doctor are independent of the number of doctors working at the hospital.

[54] "Relatively stable" means that fluctuations in demand are low relative to mean demand. Pooling a larger number of independent, similar risks in a single portfolio does not reduce the portfolio's standard deviation, but it does reduce the standard deviation relative to the mean.

The assumption of constant returns to scale seems rather optimistic. Returns to scale will typically decrease over the relevant range because of the increasing costs of control. It seems likely that extreme demands will be associated with "out of the ordinary" events, raising the probability of human and organizational errors. Studies indeed show that the difference between the planned the actual response to a crisis is often considerable (McConnell and Drennan, 2006; Quarantelli, 1988). Moreover, one might rightly ask whether it would be feasible to maintain a vast disaster response organization that is hardly ever put to work.

Let us consider the costs and gains of disaster preparedness at the margin. Denote the number of doctors by M and the maximum number of simultaneously wounded persons that a doctor can help by N_s. The largest number of simultaneously wounded persons (N_w) that could be saved by M doctors thus equals $N_w=M\cdot N_s$. To fully cope with $N_w+\Delta N_w$ simultaneously wounded persons, an additional number of doctors would be needed: $\Delta M=\Delta N_w/N_s$. But while larger demands for assistance become increasingly less likely (Figure 24), the number of doctors that is needed per patient remains the same (assumption 1).

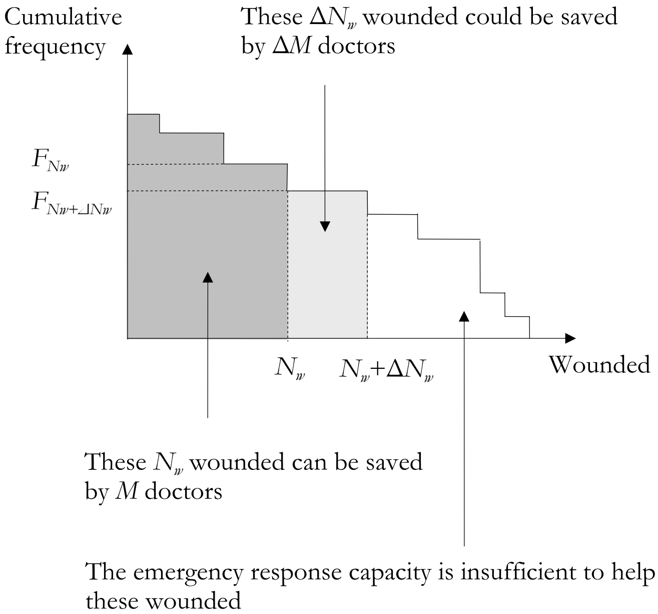

Figure 24 The cumulative frequency distribution of demand

Because of the assumption of constant marginal costs (assumption 2), the annual cost of these additional ΔM doctors equals:

$$\Delta C = S \cdot \Delta M \tag{9.1}$$

Where ΔC = annual costs of having an additional ΔM doctors; S = annual expenses per doctor.

Equation (9.1) presupposes that the capacity of a disaster response organization can be divided into infinitesimally small parts. But in reality, the supply curve is a step-function: ambulances, doctors and hospital beds come in units of one. Fortunately, the indivisibility of assets and staff seems to be of little importance when it comes to decisions about a national or regional standard of preparedness. This is because the variance of demand will be considerable for large, densely populated regions: a minor change in the desired exceedance frequency is likely to be associated with a change in demand that is considerable relative to the capacity of a single ambulance, doctor, or fire truck.

To facilitate the trade-off between investment cost and a higher standard of preparedness, all benefits and costs have to be expressed in a single unit. If, despite ethical objections, loss of life is valued in money terms, the benefit of hiring ΔM extra doctors equals:

$$\Delta B = \Delta N_w \cdot v \cdot F_{Nw+\Delta Nw} \tag{9.2}$$

Where ΔB = the annual benefits of having an additional ΔM doctors; ΔN_w = number of persons that can be saved by ΔM doctors; v = value of preventing a fatality; $F_{Nw+\Delta Nw}$ = frequency of demands for assistance that can only be met with $M+\Delta M$ doctors (per year).

The net cost of hiring an extra ΔM doctors equals:

$$\Delta TC = \Delta C - \Delta B = \Delta M \cdot S - \Delta M \cdot N_S \cdot v \cdot F_{Nw+\Delta Nw} \tag{9.3}$$

Hiring additional doctors is cost-effective as long as $\Delta TC<0$, or as long as:

$$F_{Nw+\Delta Nw} > \frac{S}{N_S \cdot v} \tag{9.4}$$

The conceptual model indicates that it would not be efficient to be fully prepared for low-probability, extreme demands. This intuitive result follows from the fact that considerable annual investments would be needed to be able to cope with rare events. Assuming $S/N_S = 10^5$ euro per year per patient (the annual costs for the medical staff, equipment, accommodation etc. needed to save the life of a patient that might turn up sometime during the year in critical condition) and $v=10^6$ euro, medical services should be equipped to deal with demands that occur (on average) at least once per decade. Although this result is obviously course[55], the order of magnitude does not appear unrealistic.

[55] Parameter values are highly uncertain and only mentioned to illustrate orders of magnitude.

9.2.2 The benefits of co-operation: scaling up

So far, the hospital has been treated in isolation. Larger accidents typically require a co-ordinated effort by organizations that, under normal circumstances, do not work together. So where do these opportunities for "scaling up" our response to large-scale accidents enter into the model?

The answer to this question lies in the left-hand side, the demand-side, of equation (9.4). The total capacity of a number of hospitals will not be affected by co-operation between hospitals. But it does influence the frequencies of the demands that each individual hospital is confronted with. "Scaling up" could be modelled as a redistribution of patients over co-operating hospitals. Such co-operation offers diversification benefits: it stabilizes the demands that all individual hospitals are confronted with. And the less volatile demand, the better we can align hospital capacity with the need for assistance.

To better understand the benefits of co-operation, we will now introduce a highly simplified model that has its roots in Markowitz's modern portfolio theory (Markowitz, 1952). Consider a group of *n* hospitals that operate in different regions and that attend to different populations under "normal circumstances". A "normal circumstance" is defined here as a situation in which none of the hospitals is confronted with a demand that exceeds its capacity. Denote the capacity of a hospital *i* by C_i. The total capacity of the group of hospitals equals $C_{tot}=C_1+C_2+\ldots+C_n$. Denote the demand for assistance per hour in each hospital's region by D_i. Aggregate hourly demand thus equals $D_{tot}=D_1+D_2+\ldots+D_n$.

Unlike each hospital's capacity, which is a constant, demand is a stochastic variable with ever larger demands becoming ever less likely. Denote the covariance between D_i and D_j by σ_{ij}, and the variance of D_i by σ_{ii}. The variance of total demand equals the sum of the variances and covariances of all the demands that the individual hospitals are confronted with, or:

$$\mathrm{var}(D_{tot}) = \sum_{i=1}^{n}\sum_{j=1}^{n}\sigma_{ij} \qquad (9.5)$$

When redistribution of patients over hospitals is possible at no extra cost or loss of health, we could always attend to all patients as long as $D_{tot}\leq C_{tot}$. Note that we could build a single huge hospital instead of a large number of smaller ones in this idealized model where returns to scale are constant and redistribution is costless. Let us however assume that the number of hospitals is greater than unity: $n>1$. If we were to always spread patients equally over the *n* hospitals, every hospital would have to deal with a demand distribution with mean (D_{tot}/n) and variance $\mathrm{var}(D^*_i)$, which equals:

$$\mathrm{var}(D^*_i) = \frac{1}{n}\sum_{i=1}^{n}\sum_{j=1}^{n}\sigma_{ij} \qquad (9.6)$$

Spreading patients stabilizes the demand that each hospital is confronted with. And as shown by equation (9.4), this reduces the (optimal) total cost as well as the (optimal) likelihood that capacity falls short. But equation (9.6) also points to another important issue. When demands in different regions are fully correlated, co-operation offers no diversification benefits at all.

Extreme demands will typically be caused by strong correlations between individual exposures. During prolonged periods of extreme heat or cold, people throughout a vast region will probably end up in hospital. Industrial accidents on the other hand are geographically localized, and large accidents in different places are unlikely to occur at exactly the same time. Scaling up could be a particularly useful strategy for such events. But even though co-operation between emergency services raises the optimal level of preparedness, it would still not make economic sense to always be fully prepared.

9.2.3 Extensions and practical implications

The conceptual model presented above is overly simplified but it does offer useful insights. It was shown that probabilistic elements (including, amongst other, considerations regarding the simultaneous occurrence of smaller events) are crucial for an evaluation of the capacity of emergency response organizations (fire brigades, police, medical aid). The conceptual model presented in the previous section can also serve as a stepping stone for more detailed analyses.

First, differences between emergency services have so far been ignored. Although the model's basic logic could easily be applied to different emergency services (e.g. police and fire brigades), input parameters would probably differ considerably. These differences concern both the demand and supply sides of equation 9.4. A police force that is equipped and trained to deal with relatively frequent protests will probably have far less difficulty (in terms of capacity) in dealing with low-probability, large-scale industrial accidents than an ambulance service.

Second, it has so far been assumed that redistribution of patients is costless and that it does not worsen the condition that patients are in. In real life, it might be detrimental to a patient’s well-being to be driven round the country in search for an empty bed. Bringing in fire trucks, ambulances and search and rescue teams from far away can take considerable time. These factors obviously limit the opportunities for frictionless diversification. And this has important implications for optimal levels of preparedness. It for instance makes economic sense to be better prepared in regions where large accidents are more likely than in regions where they are less likely. In the port area of Rotterdam, where there is a high concentration of hazardous establishments, a higher standard of preparation would be appropriate than in an area that only houses a single hazardous object. A region that houses a sizeable population should (and often is) also be better prepared than a region that houses a relatively small population. This is because fluctuations in daily demands are likely to be greater in the more populated regions.

The above is illustrated graphically in Figure 25. The figure shows the distributions of (some type of) demand for assistance in two regions. Region I is a small region with few major hazards. Region II is a highly populated region with many major hazards. A similar choice for the frequency with which the capacity of the emergency response organization is allowed to be exceeded annually (which follows from equation 9.4) works out differently in both regions. In region I, accidents involving dangerous goods could lead to demands for emergency assistance that exceed the capacity of the emergency response organization by far. But such accidents would be "business as usual" in region II. Note that the probability density functions are defined per 1/1000th year as accidents that occur simultaneously raise the instantaneous demand for emergency assistance. It is thus assumed (for reasons of simplicity) that accidents that occur within the same quarter of a day count as "simultaneous", while accidents that do not count as "successive".

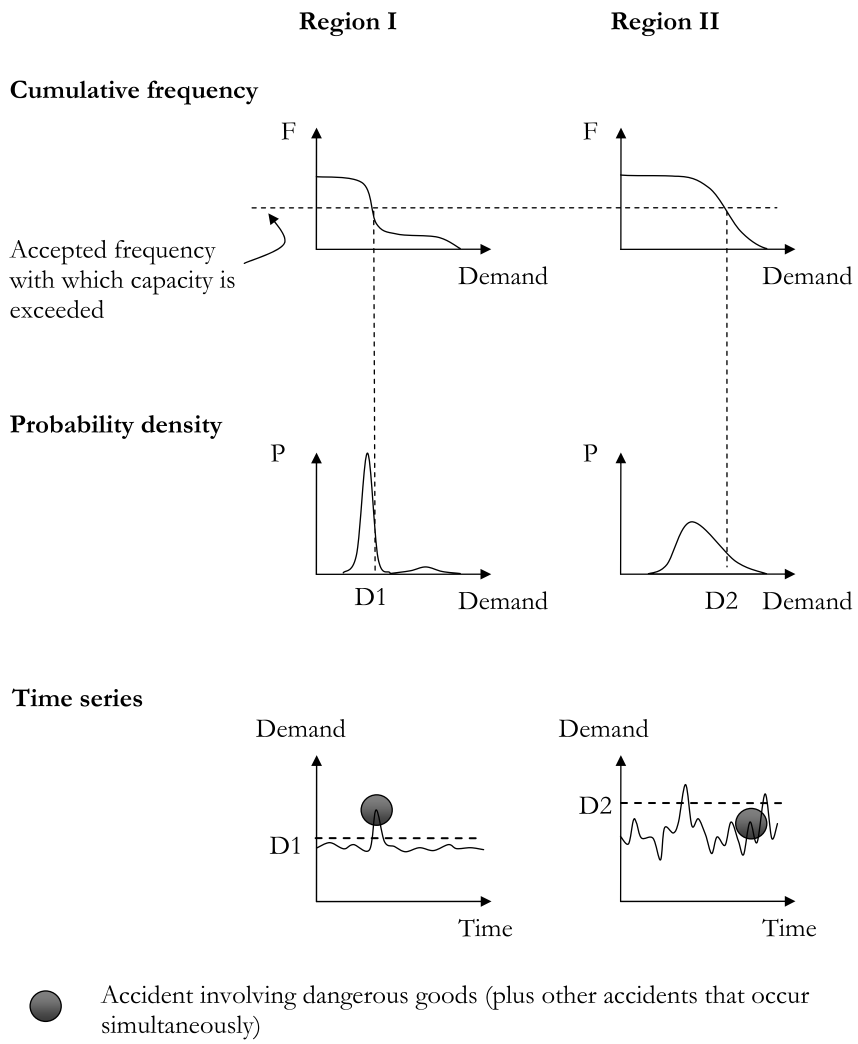

Figure 25 The cumulative frequencies per year, the probability densities (P) per 1/1000th year, and the time series of demand for two regions

9.3 The opportunity cost of disaster preparedness

So far, disaster preparedness has been treated in isolation. But as the safety chain already indicates, crisis management is an integral part of the risk management process. Budget constraints typically imply that we cannot strengthen all links of the safety chain simultaneously. And this, in turn, implies that budget allocation should be based on opportunity cost, on the value of the best alternative forgone. Would it be problematic if a link of the safety chain were to perform poorly?

An effort to improve disaster preparedness will undoubtedly do some good. But we should be careful to be satisfied with "some good". After all, a euro can be spent only once. "What if"-decision making could divert resources from links of the safety chain where these resources could have been put to greater use (Jongejan and Vrijling, 2006). The safety chain is not as weak as its weakest link. In fact, it is at least as strong as the strongest link (Jongejan et al., 2008a).

An illustrative case concerns flood risk mitigation in the low-lying Netherlands. Without its primary flood defences, the Netherlands would be swallowed by the rivers and sea. The flooding of New Orleans has shown that a major flood in a low-lying, densely populated area can have disastrous consequences. A flood in the Netherlands could have a similarly devastating impact (Jonkman, 2007). Yet interestingly, the Netherlands is poorly prepared for large-scale floods. A Flood Management Taskforce was installed in 2007 to improve disaster preparedness. But besides low-cost organizational changes and disaster planning, would it also be sensible to make considerable investments in the emergency response infrastructure and/or purchase additional helicopters to save people from their rooftops?

Maintaining a fleet of helicopters would require considerable annual expenditures, while the helicopters would be needed as little as (on average) once per century or millennium. And while helicopters might save some people from their rooftops, they cannot avoid the enormous economic impact of a major flood, nor can they prevent considerable trauma and loss of life. In fact, it seems a far more efficient strategy to prevent floods from happening in the first place. Well-intended investments in disaster preparedness could be associated with considerable opportunity cost. The position taken by the Dutch cabinet (2008) clearly reflects this view: it decided not to invest heavily in the capacities needed for mass evacuation, such as purchasing reconnaissance helicopters, boats and trucks. Instead, the government decided to take only a number of measures that would also be effective for other types of events. The cost of drastically improving preparedness for large-scale floods was simply not considered proportionate given the low probability of such events.

9.4 Conclusions

1. The Dutch emergency services would be unable to adequately deal with large-scale floods or severe industrial accidents. While this is undoubtedly regrettable, it would be unduly costly to be fully prepared for infrequent events (events that occur less often than say once per ten years).

2. It is advised to (i) define/treat the disaster that is used to evaluate the capacity of crisis management organizations in probabilistic terms[56], (ii) accept regional differences in levels of preparedness, and (iii) accept differences between the levels of preparedness of different emergency services.

3. The safety chain is not as weak as its weakest link. It is at least as strong as the strongest link.

4. Despite best intentions, a strong emphasis on disaster preparedness might lead to overinvestment and thereby give rise to excessive social cost. Second, a disproportional focus on disaster preparedness might divert scarce resources from links in the safety chain where these resources could have been put to greater use.

[56] Requiring capacity to meet "daily demands", as is current practice in the Netherlands, is in conformance with this proposal. After all, deciding on the exact definition of "daily demands" encompasses a probabilistic element: is a daily demand for instance a demand that is expected to be exceeded only once per year or less often?

Chapter 10

Flood insurance

Low-probability, large scale losses are notoriously difficult to insure. How then to deal with the damages that would occur if the Dutch primary flood defences were to be breached?[57]

10.1 Introduction: towards a private flood insurance program?

The damages caused by natural catastrophes have grown exponentially over the past decades (Munich Re, 2004). In poor countries, where flood risk mitigation is hampered by limited resources, large-scale floods are relatively frequent events. But floods can also affect wealthy nations. In 2007, extreme rainfall caused floods throughout England and Wales. With total damages amounting to 4 billion US dollar, 3 billion of which insured, it was the costliest flood ever experienced by UK insurers (Munich Re, 2008). On the 29th of August 2005, Hurricane Katrina struck the US Gulf Coast. The levee system protecting New Orleans proved no match for the ensuing storm surge and large parts of the low-lying city were flooded. Over 1400 people lost their lives. With damages totalling 138 billion US dollar, Katrina is the costliest natural disaster to date (Munich Re, 2008).

Although insurance cannot undo personal losses or take away the psychological trauma that natural disasters leave behind, it can speed up recovery and assist victims in rebuilding their lives. Low-probability disasters are however notoriously difficult to insure. Governments have intervened in a wide variety of ways to support the provision of insurance coverage (Swiss Re, 1998a; 1998b). Arrangements for the financial compensation of disaster victims can be grouped into four broad categories (after Faure, 2006; Faure and Hartlief, 2006).

First, governments could rely on voluntary insurance, supplemented with social security and ad hoc support. Germany lacks a government solution for the uninsurability of storm surges but insurance against river floods is available. Its market penetration is however low and the government has previously offered assistance to the uninsured

[57] The results of this chapter cannot readily be extended to industrial risks (see chapter 3). An excerpt of this chapter has been published as Jongejan and Barrieu (2008).

victims of river floods. After the 2002 floods for instance, the German government (and public) provided generous financial support to uninsured flood victims. Of a total loss of 11.6 billion euro, 45% was sustained in the private sector, and only 15% had been privately insured (Thieken et al., 2006).

Second, governments could require insurers to provide cat-insurance. In France, a state-guaranteed reinsurance company, the Caisse Centrale de Réassurance (CCR), was established in 1982 to provide coverage for natural disasters (Guy Carpenter, 2006; Moss, 1999). Premiums are statutorily included in first party property insurances so that market penetration is almost 100% (Swiss Re, 1998a). Whether an event is classified as a disaster depends on administrative decision. Although no government funding is involved, the CCR is guaranteed by the state. The Belgian arrangement for dealing with uninsurable floods is somewhat similar the French. In Belgium, insurance coverage against natural disasters, including floods, is statutorily included in fire insurances (although fire insurance is not compulsory) (Belgisch Staatsblad, 2005). The insurance program supplements the 1976 state-financed disaster fund that provides disaster aid by decree.

Third, governments could establish compensation funds to (partially) indemnify the victims of natural disasters. Fund build-up is a feature of several natural disaster programs, such as the California Earthquake Authority, the Florida Hurricane Catastrophe Fund, the Icelandic Catastrophe Fund and the New Zealand Earthquake Commission (Guy Carpenter, 2006). The California Earthquake Authority (CEA) was established by the state of California to insure its residents against earthquakes. The CEA is funded by premiums, contributions from member insurance companies, debt issuance, reinsurance and investment (Swiss Re, 2005). The CEA demonstrates that a calamities fund need not be funded by a government.

Fourth, governments could enter into public-private partnerships to stimulate the availability of insurance coverage. The National Flood Insurance Program (NFIP) offers flood insurance in the United States. The federal government provides underwriting capacity, and policies are written and claims are handled by insurance companies. In the United Kingdom, a "Gentlemen's Agreement" between the government and the insurance industry ensures the provision of flood insurance by private enterprise. Underinvestment in flood protection has however put the agreement under considerable strain. It has led insurance companies to differentiate premiums and reconsider the unconditional nature of insurance coverage (Huber, 2004).

As the latter example illustrates, present-day insurance arrangements are by no means perfect or static. Frequencies and impacts of natural disasters change (Munich Re, 2004), and advances in risk modelling and financial innovations continuously extend the limits of insurability (Doherty, 2000; Kielholz and Durrer, 1997; Swiss Re, 1998a). An insurance arrangement should ideally serve as an efficient mechanism for risk transfer, while providing adequate incentives for loss prevention. But deciding on appropriate (changes to existing) schemes is by no means straightforward. While some stress the need for deregulation and restraints on government relief to allow insurance markets to function (e.g. Harrington, 2000; Priest, 1996), others stress the need for government support to stimulate or supplement private sector initiatives (e.g. Cummins et al., 1999; Kunreuther and Pauly, 2006). A study about ways to increase the supply of property and casualty insurance by the US Congressional Budget Office (2002) clearly reflects these different views.

The Calamities Compensation Act[58] of 1998 provides the Dutch legal framework for the government's response to uninsurable losses. The CCA should however not be confused with an insurance program. It is a question of solidarity rather than a formal rule whether and how much compensation is actually paid, and the CCA lacks rules and procedures for the remuneration of flood victims. Also, loss payments under the CCA are, in principle, limited to 500 million euro. The damages caused by the failure of primary flood defences could easily exceed this figure: floods on the scale of New Orleans are not unthinkable (Jonkman et al., 2005). Because of the lack of clear rules and procedures, government assistance is likely to be haphazard and dictated by political considerations when disaster strikes. This is most unfortunate as poorly targeted assistance is unlikely to be efficient, as shown by the costs of uncoordinated government responses to disasters (Kunreuther and Pauly, 2006). The Calamities Compensation Act thus hardly seems to be an adequate solution for dealing with large-scale floods in the Netherlands.

Following a number of instances in which the Dutch government decided to offer compensation to the victims of natural disasters and industrial accidents under the CCA, a committee was installed to evaluate the government's framework for dealing with uninsurable losses (Disasters and Calamities Compensation Committee, 2004). One of the committee's recommendations was to consider private sector solutions for supposedly uninsurable events, a recommendation that was then turned into a cabinet decision.[59] In 2006, the Water Advisory Council then proposed the introduction of a private flood insurance program (Water Advisory Council, 2006: 17). That same year, a government taskforce took on the challenge to turn this vision into reality.

When attempting to extend the limits of the uninsurability of floods in the Netherlands, it is important to distinguish between the different types of floods damages that are currently uninsurable: these are damages caused by high ground water levels, the inundation of flood plains, and the failure of primary and regional flood defences (Kok, 2005). It would be difficult, if not impossible, to devise an efficient all-flood insurance program, given the differences between them in terms of, amongst other, potential losses and moral hazard (Jongejan, 2008). This chapter is concerned solely with the (un)insurability of floods caused by the failure of primary flood defences.

The text is organized as follows. The first section discusses six frequently debated causes of the uninsurability of large-scale floods in the Netherlands: (i) concentration, (ii) moral hazard, (iii) adverse selection, (iv) crowding out of private sector initiatives, (v) risk perception , and (vi) uncertainty surrounding risk estimates. It will be shown that concentration, moral hazard on the part of the government, and risk perception are important obstacles to the insurability of large-scale floods. The following sections build on these findings to sketch the outline of a viable and efficient insurance arrangement.

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[58] In Dutch, the Calamities Compensation Act is called the "Wet tegemoetkoming schade bij rampen en zware ongevallen", or WTS in short.

[59] "Kabinetsstandpunt naar Aanleiding van het Eindrapport van de Commissie Tegemoetkomingen bij Rampen en Calamiteiten 'Solidariteit met Beleid'" (2005).

10.2 The causes of uninsurability

When are risks insurable? Swiss Re (2005) provides a concise answer: a risk becomes uninsurable when premium rates are no longer acceptable to either insurers or the insured. Frequently debated causes of the uninsurability of large-scale floods in the Netherlands are (i) concentration, (ii) moral hazard, (iii) adverse selection, (iv) crowding out of private sector initiatives, (v) risk perception , and (vi) uncertainty surrounding risk estimates.

Concentration is a term used for the total loss potential associated with a single event. It arises from correlations between individual loss experiences.When losses are highly concentrated, regionally operating insurers will not be able to devise a portfolio of risks that is sufficiently balanced to prevent a highly volatile loss profile. A greater extent of (cross-sectional or geographical) risk-spreading can be achieved through reinsurance markets. Another option would be to securitize exposures and transfer risks to capital markets directly (Cummins, 2008). While a multi-billion euro flood loss would be unparalleled by Dutch standards, it would be dwarfed by daily fluctuations on global capital markets (Doherty, 2000; Froot et al., 1995). But despite advances in financial engineering, reinsurance against low-probability, large-scale losses still appears costly (Froot, 2001). Potential losses in the Netherlands could be in the tens of billions of euros (Ministry of Transport Public Works and Water Management, 2005). Such losses could threaten the solvency of the Dutch insurance industry. To put the size of the Dutch insurance market into perspective, consider the Dutch Terrorism Risk Reinsurance Company (NHT), a public-private partnership involving the national government, collaborating insurers, and reinsurers. The NHT provides 1 billion euro underwriting capacity for annual industry-wide terrorism-related losses in the Netherlands. The loss caused by a catastrophic flood in the western part of the Netherlands would dwarf that figure. It also seems highly unlikely that the reinsurance industry would be able to provide sufficient underwriting capacity for such floods.

Moral hazard is the prospect that an individual changes his or her behavior when a risk is transferred to a third party. It is caused by information asymmetries between insurers and policyholders: when insurers have no means to monitor and penalize excessively risky behavior, the insured lose an incentive to prevent losses (Rees, 1985a; 1985b). Deductibles, caps and coinsurance provisions are means to reduce moral hazard, but they reduce the attractiveness of an insurance purchase (see Zeckhauser (1996) for a discussion of the optimality of different ways to control moral hazard in case of catastrophic risks). Interestingly, in the Dutch case, the problem of moral hazard concerns moral hazard on the part of the national government rather than moral hazard on the part of individual citizens: flood protection in the Netherlands is publicly provided. Although individuals could take measures to reduce the consequences of floods, such measures would unlikely be cost-effective compared to measures to reduce flood probabilities. This is because the probability that a person is affected by a large-scale flood is in the order of 10^{-6} to 10^{-3} per year. The Flood Defence Act is sometimes presented as a guarantee against underinvestment in flood protection. But a recent review showed that almost 25% of the primary flood defences does not meet these standards (Ministry of Transport Public Works and Water Management, 2006), up from 15% in 2001 (Ministry of Transport Public Works and Water Management, 2001). Experiences in the UK also show that moral hazard on the part of the national government is not a purely hypothetical issue: underinvestment in flood protection has put the Gentleman's Agreement between the government and the insurance industry under considerable strain (Huber, 2004). Ex post moral hazard, i.e. the problem that insured property owners lose an incentive to avoid damages during or after floods should also be addressed. But it could be limited without considerable difficulty through deductibles or coinsurance provisions.

Adverse selection refers to a situation in which insurers cannot price coverage according to individual exposures, causing high risk individuals to be more likely to purchase insurance coverage. Just like moral hazard, it stems from information asymmetries between insurers and the insured (or from regulators that fix premium rates). When insurers cannot price coverage according to individual exposures, premium rates will have to be set at a relatively high level for low risk individuals. When insurers have no way to discern between high and low risk individuals (or price coverage accordingly), premium rates will have to be set at relatively high levels for low risk individuals. This then, reduces the attractiveness of an insurance purchase to low risk individuals so that insurers might end up with portfolios of "bad risks". Segregating risks into pools also reduces statistical variance, which positively influences premium rates. But information on the probabilities and consequences of major floods is public rather than private (see also Jaffee and Russell, 1997), and individuals have little control over potential losses. It thus seems that excessive adverse selection cannot be blamed for the uninsurability of catastrophic floods in the Netherlands.

The expected utility model predicts that all risk averse individuals would purchase fairly priced insurance. In practice however, people appear reluctant to purchase insurance against natural disasters (Kunreuther and Pauly, 2004; Slovic et al., 1977). The percentage of insured properties against floods in the Louisiana parishes affected by hurricane Katrina that struck the US Gulf Coast on the 29th of August 2005 ranged from 7.3% to 57.7% (Kunreuther and Pauly, 2006). Under the National Flood Insurance Program, homeowners could have insured their properties at an actuarially fair premium. Owners of properties constructed prior to the establishment of flood insurance rate maps could have even obtained flood insurance at a subsidized rate (Burby, 2001). Every rational risk averse individual would have purchased such reasonably priced insurance. How then to explain the low levels of coverage? Crowding out and risk perception offer two explanations.

The crowding out hypothesis holds that the market penetration of insurance against natural disasters is typically low because people expect governments and charities to offer financial support when disaster strikes. Over the past century, the US federal government has for instance increasingly offered support to the victims of natural disasters (Moss, 1999). This tendency might have bolstered expectations and created a severe moral hazard problem. According to the expected utility model, a non-zero probability of post disaster assistance reduces people's willingness to purchase insurance, as well as their willingness to take cost-effective mitigation measures (Priest, 1996; Congressional Budget Office, 2002; Harrington, 2000). Disaster relief after all reduces the loss that an individual suffers when a risk materializes. The argument is undoubtedly valid within the realm of the expected utility model. But Kunreuther (1996) found no empirical evidence that supports the notion that disaster assistance affects people's decisions to purchase coverage for natural disasters.

People's lack of interest in insurance coverage against low-probability natural disasters can also be explained by their risk perceptions. Kunreuther (1996) proposed that people first evaluate whether a risk is something to worry about, and only then decide whether an insurance purchase would be worthwhile. This sequential model is consistent with the contingent weighting model proposed by Tversky et al. (1988): individuals that are offered a complex choice will place weights on the dimensions of the problem at hand. An insurance purchase will not be considered worthwhile when people place zero weight on the probability of disaster. Experimental studies by Slovic et al. (1977) showed that individuals are more likely to purchase insurance against high-probability, low impact events than against low-probability, high impact events. To avoid a large percentage of the population ending up uninsured, coverage would have to be mandated such as in France, where every non-life insurance policy has to include comprehensive disaster coverage. Another option would be to increase awareness about the probabilities and merits of an insurance purchase, as suggested by Kunreuther and Pauly (2004).

Risk estimates for low-probability floods in the Netherlands are surrounded by considerable uncertainties. But the operation of marine insurance markets in the distant past shows that uncertainties about the frequencies and severity of losses need not make insurance impossible (Jaffee and Russell, 1997). That said, insurers appear averse to uncertainties (Hogarth and Kunreuther, 1985), and empirical studies demonstrate that insurance premiums are significantly higher for risks for which actuarially sound loss estimates are unavailable (Kunreuther et al., 1995). Advanced models have been and are being developed for estimating flood probabilities and consequences in the Netherlands. The multi-million euro FloRis-project is aimed at quantifying flood risks for all dike rings in the Netherlands (Ministry of Transport Public Works and Water Management, 2005). An important aspect that has so far been largely ignored is the simultaneous flooding of several dike rings during extreme storm surges or river discharges. Dependent failures mostly affect the tail of the loss distribution as the level of dependence is strongly determined by the extremity of the loading conditions. Cumulation therefore seems of relatively little relevance for the loss range that could potentially be privately insured.

10.3 Towards an insurance program

Given the issues of concentration, moral hazard and risk perception, government involvement would be required along two fronts (Table 9). First, the government would have to provide underwriting capacity, which would also limit the risk of underinvestment in flood protection. Second, the government would have to make insurance (semi) compulsory to avoid a large percentage of uninsured. To that end, flood insurance could be tied to fire or non-life insurance policies to increase its market penetration, as is the case in Belgium and France. Alternatively, the government could lay down rules for the remuneration of flood losses and raise premiums through the tax mechanism, thereby avoiding the cost of having to write policies and enforce a mandate. In the latter case, the government would effectively operate as a financial intermediary, just like an insurance company.

Table 9
Government interventions to resolve the uninsurability of large-scale floods

Rationale	**Intervention**	**Government role**	**Objective**
Supply-side restrictions	Provide underwriting capacity	Financial intermediary	Raise capital at an attractive rate by exploiting the government's superior creditworthiness
Demand-side restrictions	Enforce (semi-) compulsory insurance	Regulator	Avoid a large percentage of uninsured

Although a dominant role for the Dutch national government seems inevitable, government insurance/compensation programs are typically subject to strong criticisms (Priest, 1996; Harrington, 2000). The critiques mainly concern governments' limited ability to pool risks, and their poor track record in dealing with moral hazard. But these critiques do not seem to apply to the somewhat exceptional Dutch case.

First, let us consider the criticism related to cross-sectional diversification. While (re)insurance companies can pool earthquakes in Turkey, hurricanes in the US and floods in the Netherlands, the Dutch government cannot. But this does not automatically mean that Dutch taxpayers would be confronted with a considerable risk premium. While the government's ability to diversify flood risks cross-sectionally are undoubtedly limited, the government has a superior ability to diversify large-scale risks inter-temporally: the 'contract' between taxpayers and the Dutch government is a 'long term contract'. And because the national government's probability of default is negligible, it is theoretically able to borrow at the risk-free rate. The net present value of its variable loss pattern would therefore be equivalent to the net present value of a constant stream of annual losses with magnitude expected loss. If the government were to finance a loss (C) by issuing a perpetual (a bond without a maturity) at the risk free rate (r), it would pay rC annually to the bondholders. The present value of the interest payments would be rC/r =C. The loss would have been spread over an infinite time horizon without a premium for doing so. When the government is able to spread losses over time at no extra cost, it could 'sell' coverage at a price that corresponds to expected loss. Losses would have to be extreme if they were to affect the Dutch government's credit rating: a 50 billion euro loss would add roughly 25 percent to Dutch national debt.

But what about moral hazard? A government compensation program that is funded through general taxation would probably involve some degree of cross-subsidization. Fortunately, this would unlikely give rise to a severe moral hazard problem in the Netherlands. After all, flood defence in the Netherlands is publicly provided and people's contributions to flood prevention are compulsory (taxation). The issue that remains is not related to efficiency but to distributive justice. Why should someone who is not exposed to flood risk share the financial burden? The majority of the Dutch population lives in flood prone areas: over sixty percent. Given this vast percentage, it seems unlikely that people would not declare solidarity with flood victims. If however, one feels that costs should be borne exclusively by those at risk, adding risk-based premiums to the taxes paid to water boards could be a solution. That way, only those at risk would pay for flood insurance. It should be noted however that this risk premium will often be insignificant compared to the water taxes people already pay. For dike ring Central Holland, the average actuarially fair premium has been estimated at about 1 euro per household per year because of the low probability that a household suffers a loss (Kok, 2005). For other, less protected dike rings, the actuarially fair premium could be higher, although it seems unlikely that it would often exceed 100 or even 10 euro per household per year.

10.4 Involving the insurance industry?

10.4.1 Two possible roles for insurers

A dominant role for the national government does not imply that there could not or should not be a role for the private insurance industry. The private insurance industry could play two roles that could, but need not, be combined: (i) insurers could provide claims management services, and (ii) insurers could provide underwriting capacity. Contracting insurers to provide claims management services could offer advantages when insurers would be better able than the government to do so. But the government could also lay down rules for the remuneration of flood victims by law, collect premiums through the tax mechanism, and remunerate victims on the basis of e.g. modelled loss. Three layers could be discerned if insurers were to be involved as providers of underwriting capacity: self-insurance, private insurance and government assistance (Table 10).

Table 10
A flood insurance program involving a private insurance layer

	Layer	Description
1.	Self-insurance	Property-owners carry part of their losses themselves to prevent ex post moral hazard: this "deductible" is to stimulate people to keep losses to a minimum when a flood occurs or seems imminent.
2.	Private insurance	Insurance companies cover losses up to a predefined level of corporate or industry-wide loss.
3.	Government	The government auctions XOL-contracts (eXcess Of Loss-contracts, see section 10.4.2) to insurers or simply pays for losses when the second layer is exhausted. The national government's financing strategy could also involve layers, such as a calamities fund, supplemented by debt issuance (see section 10.5).

Self-insurance (a deductible) would be appropriate to prevent ex post moral hazard, i.e. to provide homeowners the incentive to take preventive action when a flood warning is issued or when a flood occurs. Different deductibles could for instance be used for property and (movable) content.

The private insurance layer would have to be relatively small (e.g. 1 billion euro) because of the costs of coverage for large, low-probability losses, and because the national government might otherwise be tempted to underinvest in flood protection. But with only a fraction of total loss covered by insurers, and a government with the ability to time diversify flood risks efficiently, one might rightly ask whether insurers should even be involved as providers of underwriting capacity.

When a private insurance layer is however contemplated, one should consider credit risk as well as the possibility that insurers will be relieved of their obligation to settle claims. The government might for instance decide to deliberately flood a polder to reduce the flood probability of a highly valuable region. Although this would obviously be a controversial decision, it is not be a purely hypothetical one. In 1998, the north-eastern part of the Netherlands was struck by high water levels. To avoid possible flooding of the city of Groningen, authorities decided to inundate the Tussenklapperpolder, a largely agricultural polder, by breaching its (regional) flood defence. The deliberate inundation was followed by legal dispute over the (party responsible for) remuneration of flood victims. When it comes to the primary flood defences, where the stakes are even higher, it seems unlikely that similar dispute would not arise afterwards.

10.4.2 The government vis-à-vis the insurance industry

If the insurance industry were to be involved in an insurance arrangement as provider of underwriting capacity, one should have regard for the role of the government vis-à-vis the insurance industry. Does the government act as a "reinsurer" that sells coverage for large-scale losses, or does it act as a "backstop" that simply absorbs losses once the private insurance layer is exhausted?

Under the arrangement proposed by Lewis and Murdock (1996; 1999), the US federal government would auction XOL-contracts for large-scale losses (25-50 billion USD) to complement existing (re)insurance markets. Payout on the XOL-contracts could follow a simple linear function of industry-wide loss (Figure 26). An XOL-contract would effectively be a call-spread: a call-option held by insurers (the government takes a long position in the losses exceeding the retention) and a put-option held by the national government (the government takes a short position in the losses exceeding the exhaustion point, the retention plus limit). Although basis risk might seem unacceptable, insurers could enter into risk-sharing agreements ex ante, as discussed by Lewis and Murdock (1996).

Although a risk loading would strictly not be needed because of the government's superior ability to time diversify (see also section 10.3), Lewis and Murdock (1996; 1999) propose a cost-of-capital adjustment to the government's risk free borrowing rate to allow the private sector to crowd out the government. Yet in the somewhat exceptional Dutch case, a dominant role for the government would actually be desirable to limit moral hazard.

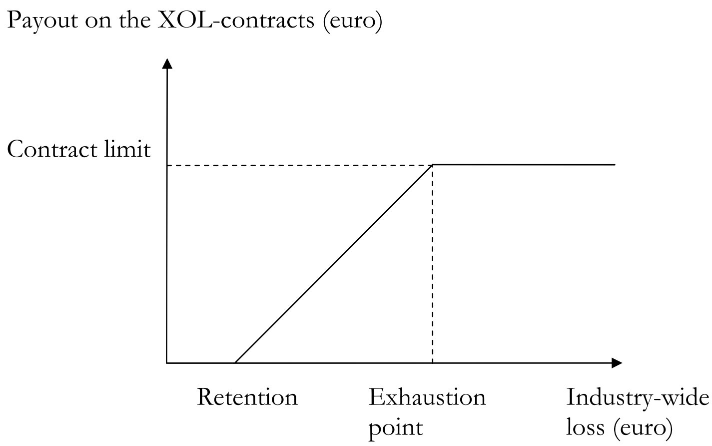

Figure 26 Payout diagram for an XOL-contract

Auctioning XOL-contracts (with (semi-)compulsory insurance) would essentially be a roundabout way to tax those at risk for a government upper layer (Table 10). But given the costs of setting up and managing a government XOL-program, it seems preferable to have the government simply raise funds through the tax mechanism. This brings us to the second possible government role; that of a backstop. The government could simply absorb industry-wide losses that exceed some predefined level. In that case, the government would essentially provide underwriting capacity while relying on insurers to settle claims.[60]

10.5 Financing government expenditures

As discussed in previous sections, an arrangement for the financing of large-scale floods in the Netherlands should involve a dominant role for the government. But how could or should the government pay for losses? There are essentially two options:

1. Ex ante: establish a calamities fund, securitize exposures (issue cat-bonds), purchase reinsurance coverage.
2. Ex post: incidentally raise taxes, issue debt when disaster strikes.

In perfect capital markets, the choice for an ex ante and/or ex post financing strategy would not influence the cost of coverage, just as a corporation's debt strategy would not influence its value (the Miller-Modigliani theorem). In that case, the government (taxpayers) would be indifferent to setting funds aside, borrowing, or a combination of both. But in the real world, the answer to the question how the government decides to raise funds *is* of interest.

[60] Cross-subsidization could be countered through the tax mechanism.

10.5.1 An ex ante financing strategy

The establishment of a calamities fund would be a way to obtain the funds needed to pay for reconstruction before a flood occurs. An advantage of a calamities fund is that funds that have been set aside are readily available when disaster strikes. This, in turn, could perhaps speed up reconstruction and thereby reduce the flood's economic impact. But despite this advantage, the establishment of a calamities fund could also have severe drawbacks. First, it could be politically difficult to earmark large reserves for the sole purpose of paying for losses that occur highly infrequently, i.e. less than once per century or millennium. The New Zeeland government for instance took $239 million from its calamities fund and used it for other purposes (Jaffee and Russell, 1997). Second, the fact that the calamities fund's assets have to be liquid reduces investment opportunities and could negatively influence returns. And finally, given the low probability of flood, it would probably take decades to establish a fund with sufficient capacity to pay for multi-billion euro floods.

Securitization could be another way to secure funding for large-scale floods upfront: the government could issue cat-bonds. A cat-bond is essentially a loan that is (partly) forgiven when a specified event occurs (Appendix V). Cat-bonds typically have a roll-over of 1-3 years so that new cat-bonds have to be issued regularly, which allows them to be adjusted to new circumstances. In 2006, FONDEN, an institution created by the Mexican government, engaged in a $160 million cat-bond transaction (MMC Securities, 2006). The cat-bonds with parametric trigger (payout based on the location and severity of an earthquake) were intended to help the Mexican government raise the funds needed to pay for its relief and reconstruction efforts in the wake of a major earthquake. The advantage of a cat-bond issuance is that funds come rapidly available when a major flood occurs. A drawback of a cat-bond issuance could lie in its costs. With $8.48 billion of total risk capital outstanding in the cat bond market (MMC Securities, 2006), a meaningful cat-bond issuance by the Dutch government would strongly affect the size of the cat-bond market. With the investors that purchase cat-bonds already concerned with the concentration of risks, as shown by the returns demanded on some hurricane cat-bonds (MMC Securities, 2006), a sizeable cat-bond issuance could be relatively costly. A final issue concerns the design of a cat-bond trigger. Cat-bonds should be triggered when the specified calamity occurs; basis risk should be taken into account.

Reinsurance could also be a way to finance floods ex ante. The government would then cede part of its exposure to reinsurers. But reinsurance for low-probability events is relatively costly (see also sections 10.2 and 10.3).

10.5.2 An ex post financing strategy

The government could raise taxes when disaster strikes to obtain the funds needed to pay for reconstruction. As governments face numerous uncorrelated risks, taxpayers would normally be confronted with relatively minor fluctuations in consumption if governments were to incidentally raise and lower taxes to maintain a balanced budget (Arrow and Lind, 1970). But raising taxes incidentally to cope with flood damages could imply considerable sudden tax increases. Moreover, a major disaster could erode the tax base, making it hard to obtain the necessary funds.

Other than mandating individuals to prioritize disaster assistance over personal consumption through higher taxes, the government could also shift its own priorities. The government's annual expenditures are well over 200 billion euro. Funds could be freed up by putting other projects to a halt. After the 1953 flood, work on a large land reclamation project in Lake IJssel stopped to free up manpower and funds to close the breaches in Zeeland. Obviously, an unexpected rearrangement of priorities might involve inefficiencies (unfinished or delayed projects) and thereby give rise to considerable social cost. While incidentally raising taxes and rearranging government budgets could be flexible strategies to (partly) finance large scale floods, they hardly seem to be attractive ones.

Funds could also be obtained ex post by issuing debt: the government could borrow the funds needed to pay for reconstruction and pay off its loan over a number of years.[61] Debt financing seems to be the way in which governments generally deal with considerable unexpected costs (not just natural disasters). Although it is sometimes suggested that EU-rules make it impossible to issue debt to pay for flood losses, an EU Member State is allowed to run a government deficit exceeding 3% of GDP when the deficit results from an "unusual event outside the control of the Member State" that "has a major impact on the financial position of the general government" (Treaty Establishing the European Community, Article 104, Stability and Growth Pact and Fiscal Surveillance, Excessive Deficit Procedure).

An advantage of debt issuance is that there is no apparent upper bound. A pay as you go strategy is also insensitive to distribution uncertainty (unlike e.g. securitization). Finally, debt issuance is highly efficient as the government is able to borrow at the risk free rate (see also section 10.3). When considerable funds have to be raised suddenly and rapidly, borrowing rates could be adversely affected. But because the Eurozone capital market (where the Dutch government sells its treasury bonds) is sufficiently liquid and deep, this price effect would likely be limited.[62] Historically, Dutch State Loan issuances over a 12 month period have regularly exceeded 30 billion euro (34 billion in 2003 and 2004, 32 billion in 2005).

10.5.3 Summary: choosing a strategy

Several methods have been discussed to finance large-scale floods. Under the assumption of perfect capital markets, the choice for an ex post or ex ante financing strategy would not affect the cost of coverage. But the real world is not that perfect. An overview of the positive and negative sides of possible financing strategies is presented in (Table 11).

[61] There might perhaps be opportunities to obtain support and/or dedicated loans from institutions such as the European Union.

[62] Source: correspondence with the Dutch State Treasury Agency.

Table 11
An overview of possible government financing strategies

Financing strategy*	**Pros**	**Cons**
Ex ante: a calamities fund	Funds readily available when disaster strikes	Early hit problem: it takes decades to build up sufficient funds while a major flood could occur next year. Political constraints on the size of a calamities fund Constraints on the type of investments (liquidity) might limit portfolio returns
Ex ante: securitization	Funds readily available when disaster strikes	A sizeable cat-bond issuance might be relatively costly Basis risk
Ex ante: reinsurance	Funds readily available when disaster strikes	Reinsurance purchases are likely to be relatively costly Credit risk
Ex post: incidentally raising taxes	Insensitive to distribution uncertainty	Sudden tax increases would have to be considerable A disaster might erode the tax base
Ex post: issuing debt	Insensitive to distribution uncertainty No strongly limiting upper bound	The borrowing rate could be (slightly) adversely affected when billions of debt have to be issued suddenly and rapidly

* Strategies could also be combined.

10.6 Conclusions

1. This chapter was concerned exclusively with the consequences of large-scale floods caused by the failure of primary flood defences. These high-impact, low-probability events are notoriously difficult to insure. The main issues concern concentration, risk perception, and moral hazard on the part of the government.

2. Without clear rules and procedures, disaster assistance is likely to be haphazard and inefficient. Because multi-billion euro losses (floods on the scale of New Orleans) are not unthinkable in the Netherlands, it would be sensible to prepare a strategy to deal with the financial consequences of large-scale floods.

3. An insurance program in which the national government provides underwriting capacity would be a viable and efficient means to resolve the uninsurability of large-scale floods in the Netherlands. Insurance companies could be involved to write policies, collect premiums, and offer claims management services. But the government could also lay down rules for the remuneration of flood victims by law, collect premiums through the tax mechanism, and remunerate victims on the basis of e.g. modelled loss. In that case, there would be little need to involve the insurance industry.

4. The national government could finance its exposure (on behalf of its citizens) in various ways. The main choice concerns timing: do we finance ex ante (by establishing of a calamities fund, by securitizing exposures, and/or by purchasing reinsurance) and/or ex post (by issuing debt)?

Chapter 11

Insurance and prevention

An insurance purchase typically reduces the cost of risk-bearing. How do mechanisms for risk transfer influence optimal investments in risk reduction?

11.1 Introduction: optimality and insurance

Quantitative risk analysis is frequently employed as a basis for deciding on investments in risk mitigation, a practice that is often linked to the expected utility framework of Von Neumann and Morgenstern (1944) and Savage (1974).[63] Amongst other, the Joint Committee on Structural Safety has embraced this framework for the comparison of decision alternatives (Faber et al., 2007), it underlies the Life Quality Index methodology that can be used to optimize measures that increase life expectancy (Rackwitz, 2004), and it serves as the basis for the optimization of flood defences in the Netherlands (Van Dantzig, 1956; Vrijling et al., 1998).

Unfortunately, the expected utility model is not as rational as is often suggested when it is applied in a context in which a single decision affects several individuals. It will be shown in this chapter that the complexities of collective choice can sometimes be avoided when mechanisms for risk transfer operate efficiently. Moreover, it will be shown that mechanisms for risk transfer can have a profound impact on optimal failure rates.

The text is organized as follows. First, the expected utility framework is introduced for the simple one person case to discuss the interplay between insurance and prevention. Insurance theory typically deals with this topic out of concern for moral hazard (e.g. Arrow, 1971; Kunreuther, 1996), but the underlying logic applies equally to the optimal design of technological systems. The expected utility framework is then extended to a setting in which a single decision affects several individuals.

[63] Von Neumann and Morgenstern (1944) and Savage (1974) construct a utility function that describes the preference ordering of a rational individual, and show that the individual, faced with uncertainty, ranks actions on the basis of the expected utility of their consequences. The idea that people maximize the expected utility of rewards rather than expected rewards themselves was first introduced by Bernoulli (1738).

11.2 The one person case

11.2.1 The rational utility maximizer

Let us first consider a single, rational decision maker that lives in world of perfect certainty. Denote the admissible set of prospects by *a*. The individual's utility function *U(a)* ranks these prospects such that:

$$a_i \geq a_j \quad \text{if and only if} \quad U(a_i) \geq U(a_j) \tag{11.1}$$

But how to rank prospects when outcomes are uncertain? Under the expected utility theorem, a rational decision maker ranks alternatives on the basis of *expected* utility (Von Neumann and Morgenstern, 1944). Let *a* now be a set of risky prospects. The decision maker's utility function would now be such that:

$$a_i \geq a_j \quad \text{if and only if} \quad E\left[U(a_i)\right] \geq E\left[U(a_j)\right] \tag{11.2}$$

The utility function is not unique: we could multiply it with a positive constant or change its base point without changing the ranking of alternatives. This has important implications when we are to consider the case of decisions that affect several individuals. But before considering decisions in a multi-actor setting, let us first consider the relations between insurance and optimal prevention for the relatively simple one person case.

11.2.2 Optimal prevention without insurance

Consider an individual that is confronted with a probability *p* of losing *q* dollars due to the failure of a technological system. He or she can reduce this probability from unity to *p(m)* by investing *m* dollars in risk reduction, where the probability *p(m)* of losing *q* dollars is a strictly decreasing function in *m*. Denote initial wealth by *w*. The optimal investment *m** can now be determined by maximizing the expected utility of total income (*x*), which is a function of *m*:

$$E\left[U(x)\right] = p(m)U(w-m-q) + (1-p(m))U(w-m) \tag{11.3}$$

Differentiating expected utility with respect to *m* yields the optimal investment *m**. This optimal investment depends, amongst other, on the shape of the utility function. A risk averse individual that considers the risk less pleasant than a certain loss with magnitude expected loss will invest more than a risk neutral person. Conversely, a risk seeking individual will invest less.

12.2.3 Optimal insurance

Let us now consider a rational utility maximizer that contemplates an insurance purchase. The individual is faced with a fixed probability p_0 of suffering a loss *q*. Denote the amount of damage that can be reclaimed under the insurance contract by *c*, the annual cost per unit coverage by *z*, and initial wealth by *w*. The optimal amount of coverage (*c**) can now be determined by maximizing the expected utility of total income (*x*), which is now a function of *c*:

$$E\left[U(x)\right]=p_0U(w\text{-}q+c\text{-}zc)+(1\text{-}p_0\ )U(w\text{-}zc) \qquad (11.4)$$

When the individual's utility function is concave (risk averse behaviour), the optimal amount of coverage can be found by differentiating expected utility with respect to *c*. The optimum c^* is bound between zero and maximum loss (after Kunreuther and Pauly, 2006). When $c^* \leq 0$, the rational utility maximizer does not purchase coverage. When $c^* > q$, he or she purchases full coverage ($c^*=q$) as it is impossible for claims to exceed total loss *q*.

11.2.4 Optimal prevention with insurance

The loss probability was treated as a constant in the previous section. Let us now assume that it depends on the investment in risk reduction (*m*), as in section 12.2.2. Note that the cost per unit coverage (*z*) will depend on *p*, and hence on *m*. It will after all be less costly to purchase insurance coverage when the probability of suffering a loss is 1/10000 rather than 1/10. The cost per unit coverage will thus be a strictly decreasing function in *m* of the investment in risk mitigation ($dz/dm<0$). To determine the optimal amount of insurance coverage (c^*) and the optimal investment in risk reduction (m^*), we have to maximize the expected utility of total income (*x*), which is now a function of *m* and *c*:

$$E\left[U(x)\right]=p(m)U(w\text{-}q+c\text{-}z(m)c\text{-}m)+(1\text{-}p(m))U(w\text{-}z(m)c\text{-}m) \qquad (11.5)$$

The outcome of the optimization depends, amongst other, on the cost of coverage. But what insurance premium could be expected? The failure of technological systems is generally uncorrelated with market returns. When mechanisms for risk transfer operate efficiently, technological risks should cost expected loss (see also chapter 10). If full insurance coverage were to cost $p(m)q$, the expected utility of total income would equal:

$$E\left[U(x)\right]=U(w\text{-}p(m)q\text{-}m) \qquad (11.6)$$

We would now be able to determine an optimal investment in risk mitigation without having to worry about the exact shape of the decision maker's utility function (as long as it is not convex). In fact, the decision problem could be formulated as if our decision maker was risk neutral:

$$Max\left[E\left[U(x)\right]\right]=Max\left[w\text{-}m\text{-}p(m)q\right] \qquad (11.7)$$

or (note also the irrelevance of initial wealth *w*):

$$Min\left[m+p(m)q\right] \qquad (11.8)$$

Besides the advantage of no longer having to specify a utility function, another important result is that we would overinvest in risk reduction if we were to ignore the opportunities for risk transfer. Capital markets allow us to diversify exposures and thereby reduce the cost of risk bearing (provided capital markets operate efficiently and people are risk averse). An investment in system safety thus cannot be evaluated without concern for the way potential losses are borne.

11.3 The benevolescent despot: the multi-actor case

11.3.1 The optimization of public safety without insurance

Many decisions concerning the safety of engineered systems affect a public rather than a single individual. Infrastructures such as tunnels, flood defences and high speed rail links are generally paid for through general taxation, requiring all taxpayers to contribute. And failures of technological systems often affect several individuals as well. How to decide on an optimal investment in risk reduction if this decision is to be based on individual preferences?

The single decision maker framework could be extended to this multi-actor setting by considering what a benevolescent decision maker would decide given the public's appraisal of every decision alternative. But the public is merely a collection of individuals. When every individual prefers prospect a_1 over a_2, we could say without much difficulty that the public prefers a_1. But what if the public is divided and ten percent of the population preferred a_2? The approach that is commonly taken to overcome this dilemma is to consider the aggregate or population-averaged costs and gains of different prospects. This practice is based on the Kaldor-Hicks potential compensation criterion that allows us to consider total output and distribution apart (Pearce and Nash, 1982). But despite its widespread use, Arrow cautions us that "there is no meaning to total output independent of distribution" (Arrow, 1963: 40).

As discussed in section two, a person's utility function is defined up to a positive affine (positive linear) transformation under the expected utility theorem. Without a single scale and the possibility to meaningfully compare the intensities of people's likes and dislikes, it would be impossible to construct a ranking of alternatives on the basis of total public pleasure. But how to meaningfully aggregate people's pleasures and pains? The aggregation of individual preferences presupposes cardinal utility and the interpersonal comparability of utility, two assumptions that are not uncontested. If, however, these assumptions are accepted, a benevolescent despot that is solely interested in the aggregate utility of the population should rank risky prospects such that:

$$a_i \geq a_j \quad \text{if and only if} \quad \sum_{k=1}^{n} E\left[U_k(a_i)\right] \geq \sum_{k=1}^{n} E\left[U_k(a_j)\right] \qquad (11.9)$$

Where n denotes the number of individuals that would be affected by a decision. Unfortunately, additional assumptions are unavoidable if we are to evaluate total output using a single utility function for aggregate gains and losses that is based on individual (cardinal) preferences. To be sure that such a utility function always yields valid results, it has to be assumed that all individuals have linear and equal utility functions. The first implies risk neutral behaviour, and the latter implies that the marginal utility of income is constant across individuals. Both assumptions seem unrealistic. People are typically risk averse, and it is unlikely that an extra dollar in the hands of a millionaire brings the same amount of pleasure as an extra dollar in the hands of a poor man.

Optimizing the safety of technological systems is clearly not without considerable difficulty. The expected utility framework can be extended to a multi-actor setting, but only when additional (disputable) assumptions are made. In defence of the optimization of total output, one might argue that its ramifications remain limited when the "unfair" distributive consequences of a large number of decisions cancel out. This, however, need not be the case.

11.3.2 Insurance, investment cost and optimal prevention

The presence of efficient mechanisms for risk transfer could strongly reduce the theoretical and normative dilemmas that surround the use of the expected utility framework in a multi-actor setting. When insurance markets operate efficiently, every risk averse individual will purchase full insurance coverage. Every individual's cost of risk bearing then equals expected loss, irrespective of his or her exact risk preferences. But to allow for further simplification, we also have to consider the distribution of investment cost.

Investment cost will often be concentrated in the hands of a few, but sometimes they are dispersed throughout a wider community. To maximize aggregate public pleasure (assuming cardinal utility and interpersonal comparability), the financial burden should be placed on those with the lowest marginal utility of wealth. This, however, presupposes knowledge of individual utility functions.

When there are rules that ensure that contributions to system safety are proportionate to individual exposures, the complexities surrounding the optimization of public safety can be strongly reduced. When perfect insurance is available, i.e. when full coverage is available against the actuarially fair premium (expected loss), and when expenditures are distributed in proportion to individual exposures, the optimization of system safety could be reduced to a simple expected value optimization. Consider for instance two individuals that are faced with an event with probability p that could cause them to lose q_1 and q_2 respectively ($Q=q_1+q_2$). They could reduce this probability from unity to $p(M)$ by investing m_1 and m_2 in risk reduction ($M=m_1+m_2$), with $\mathrm{d}p(M)/\mathrm{d}M<0$. Let us assume that they could purchase full insurance coverage against the actuarially fair premium. When the individuals are risk averse, they would both purchase full insurance coverage, costing them $p(M)q_1$ and $p(M)q_2$ respectively. The first individual now wishes to minimize her expenditures (similarly for the second individual):

$$Min\left[m_1 + p(M)q_1\right] \tag{11.10}$$

With:

$$m_1 = M\frac{p(M)q_1}{p(M)Q} = M\frac{q_1}{Q} \tag{11.11}$$

Substitution of (11.11) in (11.10) yields:

$$Min\left[q_1 \frac{M}{Q} + p(M)q_1 \right] \tag{11.12}$$

Or:

$$Min\left[M + p(M)Q \right] \quad \text{(similarly for the second individual)} \tag{11.13}$$

As shown by equation 11.13, the interests of both individuals are perfectly aligned and none of them can be made better off when aggregate expenditures are minimized under the condition of risk neutrality. When mechanisms for risk transfer operate efficiently, individuals are risk-averse (or risk neutral), costs are borne in proportion to individual exposures, and the initial distribution of wealth is fair, we could reduce the optimization of system safety to a risk neutral minimization of expenditures. Unfortunately, it seems unlikely that any of these conditions will ever be completely met. While investment cost and exposures might for instance be distributed in a *fairly* proportional way, it seems unlikely that they will ever be distributed *exactly* so. And perfect insurance presupposes that all consequences of failure can be compensated for, that insurance is offered against the actuarially fair premium (expected loss), and that full compensation is so frictionless that people do not even notice that they have suffered a loss. The optimization of risks to the public thereby typically involves a trade-off between practicality and scientific rigour.

11.4 Case study: the optimization of flood protection

11.4.1 The economic decision problem

Insurance and risk mitigation are closely linked. This section deals with optimal investments in flood prevention assuming the absence of moral hazard. Ever since the 1950s, the design standards for the Dutch flood defences have been based on/rationalized by risk neutral cost-benefit analyses. The optimal standard of protection is found by minimizing the discounted costs of dike strengthening and the discounted expected value of future losses (after Van Dantzig, 1956):[64]

$$Min\left[NPV \right] = Min\left[M + \int_0^T pQe^{-rt}\,dt \right] \tag{11.14}$$

Where NPV = net present value of total cost (euro); M = total investment in flood defence (euro); p = probability of flood (per year); Q = total damage in case of flood (euro); T = planning horizon (year); r = discount rate (per year).

[64] A simplified one-period model without economic growth or sea level rise is presented here for illustrative purposes. It is assumed that the NPV of the cost of a delayed program exceeds the NPV of the cost of direct investment.

When overtopping is the only failure mode of a flood defence, and when exceedance frequencies of water levels can be described by an exponential distribution, the failure probability p equals:

$$p = e^{-\frac{h-a}{b}} \tag{11.15}$$

Where p = probability of failure; h = dike height (m); a, b = constants (m). When it is assumed that the costs of dike heightening consist of a fixed and a variable part, equation (11.14) can be expanded to:

$$Min\left[NPV\right] = Min\left[M_0 + M'h + \int_0^T e^{-\frac{h-a}{b}} Qe^{-rt}\,dt\right] \tag{11.16}$$

Where M_0 = fixed cost of dike heightening (euro); M' = variable cost of dike heightening (euro/m); h = dike height (m); a, b = constants (m).

The optimal standard of protection (h^*) can now be found by differentiating NPV with respect to h. Figure 27 shows how the net present value of total cost changes when flood defences are raised (fictitious parameter values). The optimal height of the flood defences is 5.5m. As shown by Figure 27, the regret of overinvestment in flood defence is typically lower than the regret of underinvestment.

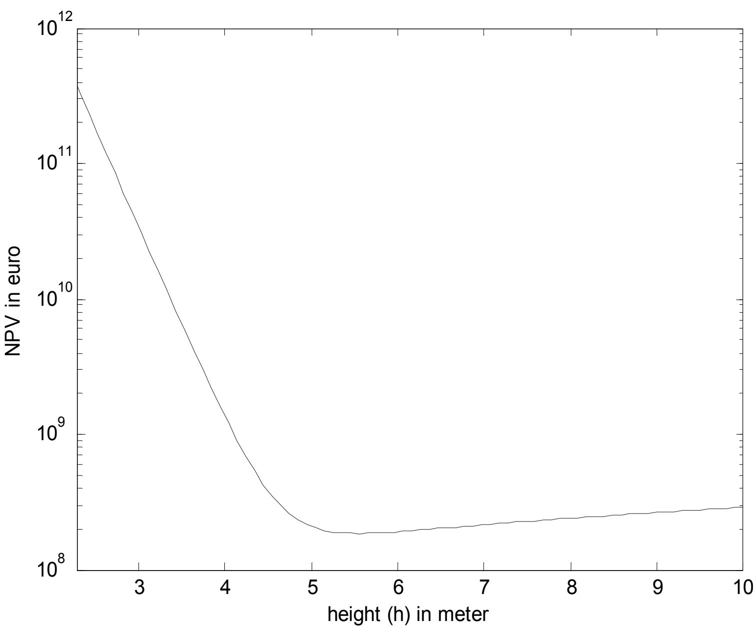

Figure 27 Optimal investment in flood protection under risk neutrality; M_0=40.10^6 euro; M'=25.10^6 euro/m; a=2.3m; b=0.3m; r=0.015/yr; Q=10.10^9 euro.

While the outcomes of cost-benefit analyses for flood protection are subject to considerable uncertainties because of the low-probability nature of large-scale floods, cost-benefit analyses can be useful for illuminating tradeoffs and for rationalizing investments in flood protection. After the catastrophe that struck New Orleans, an advisory report was prepared by Dutch experts in the field of water and flood risk management, discussing ways to protect coastal Louisiana from floods (Netherlands Water Partnership, 2007). The report evaluated New Orleans Metropolitan Area's 1/100 per year standard of protection, which is a customary standard in the US. The outcomes of a preliminary cost-benefit study showed that a considerably higher standard of protection could be justified on economic grounds. The optimal level of protection was found to be in the order of 1/1000 to 1/5000 per year, a result that proved rather insensitive to changes in flood damage estimates, investment costs, and the discount rate (Jonkman et al., 2008).

11.4.2 Relaxing the assumption of perfect insurance

Equation (11.16) presupposes risk neutrality. But why should a benevolescent despot only consider expected loss when citizens are risk averse? Interestingly, equation (11.16) shows considerable resemblance to equation (11.13) which presupposed the availability of perfect insurance and proportionate contributions to system safety. Of these two conditions, the availability of perfect insurance seems particularly contestable.

Flood risks in the Netherlands are highly concentrated: a single flood could give rise to billions of euros of damages. As discussed in chapter ten, private insurance against large-scale floods is currently unavailable in the Netherlands. The assumption of perfect insurance might therefore seem highly unrealistic. But the assumption of perfect insurance does not presuppose the provision of insurance by private enterprise. When a government is trusted to provide swift and complete compensation for losses, the assumption of a negligible risk premium could be fully justifiable. Indeed, the Delta Committee assumed that funds would be set aside to cover future losses and it treated the economic decision problem as "an insurance problem" (Van Dantzig, 1956).

So far, it has been assumed that all losses could be compensated for. But as recently shown by the flooding of New Orleans, the human tragedy of a large-scale flood extends well beyond the loss of property and income. Floods can disrupt communities and families, and leave considerable trauma behind. It would be unreasonable if not immoral to argue that decision makers and engineers should ignore these aspects and only consider the economic impacts of the failure of technological systems. The approach that was followed by the Delta Committee was to multiply potential economic damage with a constant (equal to two) to account for intangible losses. Distress and loss of life were thus assumed to be proportionate to economic loss. This practical solution allowed decision makers to evaluate the influence of intangible losses on their optimizations. The decision problem was thus reformulated to:

$$Min\left[M_0 + M'h + K\int_0^T e^{-\frac{h-a}{b}} Qe^{-rt}\,dt \right] \qquad (11.17)$$

Where K = multiplication factor to account for intangible losses. The optimal height of a flood defence, and hence the optimal investment in flood protection, goes up when the multiple of expected loss increases. As shown in Figure 28, the optimal height of the flood defence is about 6 meters when the certainty equivalent is five times expected loss.

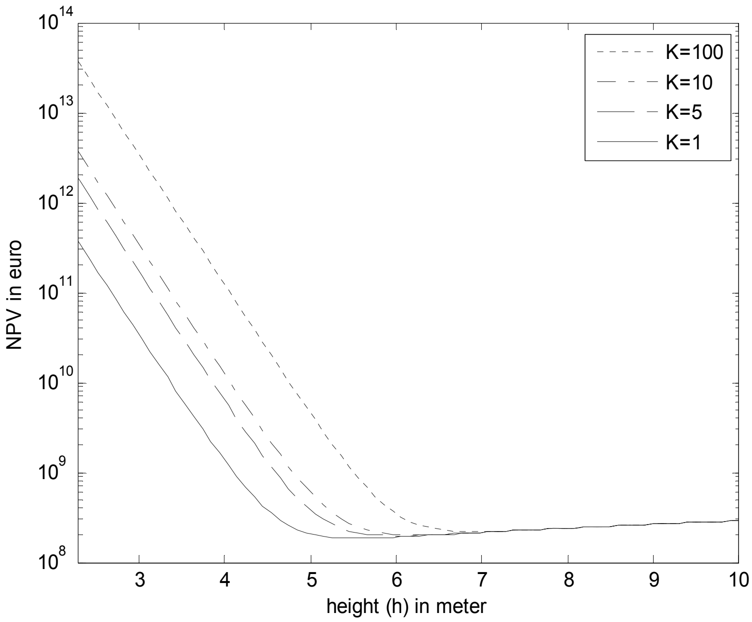

Figure 28 Optimal investment in flood protection under *K* times expected loss; M_0=40.10⁶ euro; M'=25.10⁶ euro/m; a=2.3m; b=0.3m; r=0.015/yr; Q=10.10⁹ euro.

How would the availability of a less-than-perfect insurance arrangement influence the optimal standard of protection? Reinsurance premiums for low-probability, large-scale losses are typically a multiple of expected loss (Froot, 2001). If a reinsurance contract is assumed to be priced as a multiple of expected loss, we could use equation (11.17) to account for the costs of coverage in the optimization of a flood protection system (see also Kok et al., 2002). The supposed pricing rule is clearly imperfect, but it serves its purpose of illustrating how any pricing rule that accounts for probabilities and consequences and that leads to a premium rate that exceeds expected loss influences the optimal standard of protection. Results are shown in Figure 28. For *K*=1, the optimal height of the flood defences equals 5.5m. But if (re)insurance were to cost ten times expected loss (*K*=10), the optimal height of the flood defences rises to 6m. The example shows that the efficiency of a flood insurance program and the optimal investment in flood protection are closely linked.

The formulation of the decision problem has to be adjusted considerably if the availability of flood insurance (or government compensation) is considered unrealistic. That could for instance be the case if the government were to signal its unwillingness to provide compensation for flood damages.[65] We would then have to consider each individual's utility function, and the distribution of initial wealth, investment costs, and risks to maximize aggregate utility. To reduce the complexities of the decision problem to manageable proportions, let us assume that wealth effects are absent, that exposures and investment costs are uniformly distributed over the population, and that everyone has the exact same utility function. Everyone's interests are thus perfectly aligned, implying that every individual prefers the same public investment in flood protection. The decision problem can now be reformulated to:

$$Max\left[-M_0 - M'h - \int_0^T C_{p,Q} e^{-rt} dt\right] \tag{11.18}$$

Where $C_{p,Q}$ = certainty equivalent for a loss Q with annual probability p (euro).

Utility functions of the form $U(x)=1-e^{-\gamma x}$ describe behaviour that is independent of wealth effects. The constant γ is the Arrow-Pratt coefficient of constant absolute risk aversion (CARA): $\gamma=-U''(x)\ /U'(x)$ (Chavas, 2004). The greater the value of γ, the stronger the degree of risk aversion, and the stronger the certainty equivalent exceeds expected loss. The certainty equivalent ($c_{p,q}$) of an individual suffering a loss q ($q=Q/n$) with probability p can be calculated as follows:

$$pU(w-q)+(1-p)U(w-q)=U(w-c_{p,q}) \tag{11.19}$$

$$p\left(1-e^{-\gamma(-q)}\right)=1-e^{-\gamma(-c_{p,q})} \tag{11.20}$$

Hence

$$c_{p,q}=\frac{1}{\gamma}ln\left(pe^{\gamma q}-p+1\right) \tag{11.21}$$

Note that the above expression converges to expected loss (pq) when $\gamma\rightarrow 0$ (risk neutrality). The decision problem can now be written as:

$$Max\left[-M_0 - M'h - \frac{n}{\gamma}ln\left(e^{-\frac{h-a}{b}+\gamma q} - e^{-\frac{h-a}{b}} + 1\right)\int_0^T e^{-rt} dt\right] \tag{11.22}$$

Risk aversion raises the optimal investment in flood protection (see also Figure 29). The outcomes are extremely sensitive to the choice for a coefficient of constant absolute risk aversion (γ) because of the high consequence nature of large-scale floods.

[65] As discussed in chapter 10, any insurance program for dealing with large-scale floods in the Netherlands would require a dominant role for the national government.

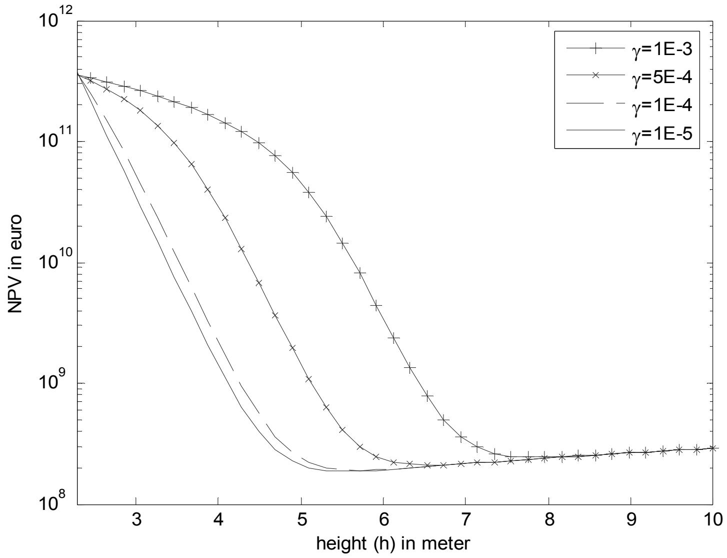

Figure 29 Optimal investment in flood protection under constant absolute risk aversion; M_0=40.10[6] euro; M'=25.10[6] euro/m=2.3m; b=0.3m; r=0.015/yr; Q=10.10[9] euro; n=10[6] persons.

So far, we have assumed that individuals display constant absolute risk aversion (CARA). Despite the practicality of this assumption, the exponential utility curve places constraints on individual risk behaviour that hardly seem realistic. After all, it seems unlikely that people's pains depend on the absolute severity of losses, rather than the severity of losses relative to initial wealth. Relaxing the assumption that wealth effects are absent thus seems reasonable. Iso-elastic utility functions describe behaviour that corresponds to constant relative risk aversion (CRRA) (Chavas, 2004):

$$
\begin{aligned}
&U(x)=x^{(1-\varphi)} && \text{for} \quad \varphi<1 \\
&U(x)=\ln(x) && \text{for} \quad \varphi=1 \\
&U(x)=-x^{(1-\varphi)} && \text{for} \quad \varphi>1
\end{aligned} \tag{11.23}
$$

Where φ denotes the Arrow-Pratt coefficient of relative risk aversion ($\varphi=-xU''(x)/U'(x)$). This coefficient can be interpreted as an elasticity: it expresses the percentage decrease in marginal utility due to a percentage increase in wealth (Chavas, 2004). Unfortunately, the use of a CRRA utility function requires us to drastically reformulate the objective function. Let us assume that per capita wealth is constant. Denote per capita wealth by w and every individual's contribution to flood defence by m (with $m_0=M_0/n$ and $m'=M'/n$). The maximization of aggregate expected utility now boils down to (φ=1): [66]

[66] Arrow (1971b) has shown that the coefficient of relative risk aversion should generally be around one. For the utility function to be bounded from above (when wealth goes to infinity), φ

$$Max\left[p\,ln\left(w - m_0 - m'h - \int_0^T qe^{-rt}\,dt\right) + (1-p)\,ln\left(w - m_0 - m'h\right)\right] \qquad (11.24)$$

Figure 30 shows how relative risk aversion influences the optimal investment in flood protection. For φ=1 and a loss that equals 50% of wealth, the optimal height increases from 5.5m to 5.7m. For φ=2 and a loss that equals 75%, the optimal height increases to 5.9m. The impact of relative risk aversion on the optimal investment thus seems limited (within the range of *K*=1-4 in equation 11.18). And given the disputable assumptions that again had to be made, the Delta Committee's relatively simple, insightful model (*K* times expected loss) seems preferable over this more refined yet less insightful one.

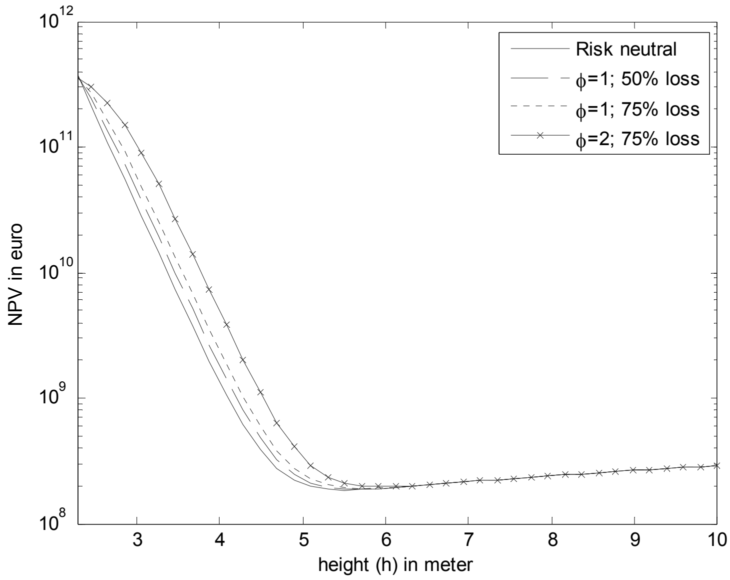

Figure 30 Optimal investment in flood protection under constant relative risk aversion; M_0=40.10^6 euro; M'=25.10^6 euro/m=2.3m; *b*=0.3m; *r*=0.015/yr; *Q*=10.10^9 euro; *n*=10^6 persons.

has to be lower than one; and for the utility function to be bounded from below (when wealth goes to zero), φ has to greater than one. For φ=1, the CRRA utility function takes the form of the natural logarithm.

11.5 Conclusions

1. The expected utility framework developed by Von Neumann and Morgenstern provides a rational basis for the evaluation of risks and the optimization of system safety within the context of a single decision maker. Yet most decisions about system safety concern risks to a public. When decisions are to be based on the preferences of all potentially affected individuals, the expected utility framework has to be supplemented with several disputable assumptions. When analysts for instance consider population-wide or population-averaged effects, they are implicitly making assumptions about the comparability of individual preferences. While the consistent optimization of total output might make everyone better off in the long run, this need not be the case.

2. Efficient mechanisms for risk transfer reduce optimal investments in system safety. This has been illustrated for the design of flood defences in the low-lying Netherlands: the availability of an efficient flood insurance program would reduce optimal investments in flood defence to a minimum (see also Jongejan and Barrieu, 2008b).

3. Risk neutral cost-benefit analyses for flood protection already implicitly assume the availability of full and fairly priced insurance (or risk neutral behaviour). The introduction of an insurance program thus cannot be used as an excuse for not meeting flood safety standards (derived from risk neutral cost-benefit analyses) or as a justification for lower levels of protection.

Part IV

Main results

Chapter 12

Conclusions and recommendations

Given the results of the analyses presented in previous chapters, what advice could be given to policymakers? Before considering the conclusions and recommendations of this paper, let us first briefly reflect on the methodological choices that have so strongly influenced them.

12.1 Reflecting on methodological choices

The central objectives of this study were to evaluate current regulatory practices in the domains of industrial and flood safety in the Netherlands, and to formulate proposals for improvement. Policy evaluation and policy formulation are by no means purely scientific, objective tasks. In a value-laden study like this, care should be taken not to confuse positive and normative analysis. An economic framework was used to describe, explain and predict. The utilitarian perspective taken throughout this thesis did not require us to value everything in money terms. For illuminating basic trade-offs, it only had to be assumed that different values are exchangeable and that people prefer more over less. That is, we had to assume that people prefer more wealth and safety over less.

The appraisal of policy alternatives is a task that requires a yardstick to distinguish between good and bad. Throughout this thesis, social improvements have been defined in a way that is consistent with the approach followed in societal cost-benefit analyses. While cost-benefit analysis is often seen as an objective procedure to optimize or rationalize social choice, the same could arguably be said about majority voting. While voting on the basis of dollars might sometimes be seen as most appropriate (the organization of social life through the market mechanism), we might prefer the organization of social life through the political system (one man, one vote) in other cases. When people hold different preferences, collective decision making inevitably involves a set of subjective, disputable assumptions.

The ethic that underlies this thesis is strongly related to liberalism, a normative theory concerning the organization of social life. Liberalism's emphasis on individual freedoms is founded on a utilitarian ethic: people themselves are considered to be the only true judges of their personal likes and dislikes. But because many desirable things in life are scarce, people's wants can conflict. Without a delimitation of rights, freedom would soon degenerate into Hobbesian fear. This position is well articulated in the "Two Treatises of Government" by John Locke, one of the founding fathers of liberalism (Locke, 1698 (1998)). Rules thus have to made and enforced. But there would be no merit in government intervention for its own sake.

The analyses presented in this dissertation most closely fit an instrumental view on democracy, i.e. democracy as a means to arrive at collectively binding decisions whilst preventing arbitrary rule. Some democratic theorists would surely object, arguing that democracy is also an end in itself (see also Held, 1996 for an overview of democratic thought). In liberal democracies, bureaucracies derive their authority from rules and procedures that have been established by democratic institutions. Decisions about land-use planning in the vicinity of hazardous establishments in the Netherlands are sometimes said to be technocratic and little democratic[67]. But these decisions are based on rules that have been laid down in laws that have passed Parliament. We could however also think of other ways to arrive at collectively binding land-use planning decisions. Dahl (1989; 1991) for instance proposed the introduction of randomly composed citizen panels to assist political decision making. While that might seem unfeasible, it is important to realize that we are limiting the scope of our analyses by keeping certain variables fixed.

A final remark seems in place concerning the choice to limit the scope of this study to non-malicious threats. Terrorism has gained a prominent place on the political agenda since the 9/11 attacks on the World Trade Centre in New York. The decision to exclude malicious threats from this study was based on a number of considerations. Risks related to acts of sabotage or terrorism require strongly different protective measures than risks related to non-malicious threats. Terrorist threats could be perceived as adaptive loads that adjust themselves to the protective measures that have been put in place. Static design standards and regulations therefore provide little assurance. And in some cases, safety and security may conflict. While openness allows governments and citizens to anticipate, scrutinize, and control, it can also show where organizations and communities are most vulnerable. Although these tensions need not be severe, they are not purely speculative. Effect distances were for instance removed from the publicly accessible risk maps in the Netherlands in 2005. As discussed by the bill's explanatory memorandum (2005), this was done to make it harder for terrorists to pick their targets. There is also a much more important issue that sets the mitigation of malicious threats aside. Effective measures to reduce the probability of a terrorist attack could have severe consequences for individual freedoms. Are these dangerous and illegitimate (as argued by e.g. Böhler, 2004; Van Gunsteren, 2004) or are infringements of basic human rights the "lesser evil" in the fight against terrorism, as argued by Ignatieff (2005)? With civil liberties and the constitutional state at stake, I strongly believe that the political and legal dimensions of anti-terrorism policies deserve a separate, in-depth treatment.

[67] Democracy comes in a wide variety of forms. Popular claims that risk decision making ought to be "democratized" frequently ignore the differences between different streams of democratic thought.

12.2 Summarizing the main conclusions

The main conclusions of this dissertation are listed below. The list consists of the most important conclusions of the preceding chapters. It should be kept in mind that they all rest on a consequentialist utilitarian ethic. Different approaches would undoubtedly have yielded different conclusions. But understanding where a cost-benefit framework does *not* get us is arguably just as important as understanding where it *does*.

1. Risk appraisal is a value-laden activity. No person can rightfully claim to possess superior knowledge about the risks that ought to be acceptable to all. Suggestions to "democratize risk decision making" or to "increase public participation" provide no easy way out of the normative dilemmas that surround public choice. For who should participate in decision making, and how should participation be organized? Should every person's vote be given a similar weight? These and other questions cannot be answered without making value judgments. Economic analyses of decision making under uncertainty often consider a single rational decision maker. But when a decision affects several individuals, this single decision maker framework is no longer as objective or rational as is often suggested. The difficulties surrounding social choice need not lead to mindless relativism however. Scientists can assist decision makers by clarifying problems, by pointing to key variables, and by illuminating trade-offs. (chapter 1)

2. Risk regulation is a balancing act. Risk should therefore not be singled out as the only factor driving decisions: risk is only part of the bigger picture. A focus on risks alone can easily lead to inappropriate policy recommendations. Risk can in itself not be a justification for government intervention. Although the severity of a risk points to the maximum gains that could be brought about by an intervention, it says little about the costs of the intervention (including gains forsaken). Government intervention implies a change in current conditions. It is this change that should be judged on its merits, not the point of departure. (chapter 2, chapter 8)

3. A necessary condition for government intervention lies in the presence of market failures (equity apart). In a world without market failures, every individual that pursued his or her private interests would also act in the interest of all. Unfortunately, markets sometimes fail to allocate resources efficiently. Market failures include negative externalities (third party risks), public goods (flood defence), and imperfect information. The government can intervene in a variety of ways: it can coerce its subjects (enforce rules), change the incentives structure (subsidies, taxes) or provide services itself. (chapter 2)

4. Although market failure is a necessary condition for government intervention, it is by no means a sufficient one. Government intervention can be a costly affair. Staffing ministries and inspectorates comes at cost. And costs imposed on private enterprise will find their way into profits and/or product prices. Non-intervention is an alternative that could easily be overlooked. The choice for

government intervention should be based on opportunity cost, on the value of the best alternative forgone. (chapter 2)

5. Government interventions should not be evaluated in isolation. Through taxes, subsidies, rules, and the provision of services, the government influences the behaviour of individual market participants. The stringency of new rules should depend on the policies that have already been put in place. After all, the consequences of different measures might overlap. Stringent societal risk criteria could for instance be a substitute for a combination of less stringent societal risk criteria and more stringent liability rules. Without concern for such interdependencies, one is likely to create overdeterrence. And given the utilitarian position that risk regulation is a balancing act, neither too much nor too little risk comes to the benefit of society. (chapter 3)

6. The polluter pays principle should not always be used as a guide for risk decision making. When the market does not function properly, the principle could stimulate polluters to take relatively cost-ineffective measures. (chapter 3)

7. The ALARA principle (As Low As Reasonably Achievable) is often interpreted as the continuous effort to reduce risks to the public. From a utilitarian perspective, the asymmetry that is implied by this interpretation hardly seems reasonable. Under a utilitarian definition of "reasonable", ALARA simply refers to the effort to balance (marginal) costs and gains. Risk reduction beyond stand-still could be considered broadly reasonable in case of intensifying demands for a safe society and/or technological innovations that make safer technologies less costly. But one could also think of situations in which the costs of risk mitigation increase (think of e.g. the changing tone of the debate on nuclear power), or socio-economic changes that affect the marginal utility of safety relative to wealth (e.g. economic downturn). (chapter 3)

8. A recurring theme in debates about flood risk management in the Netherlands is that flood defences worsen rather than reduce flood risks by hindering sedimentation. Although it sounds attractive to leave deltas untouched and to rely on natural processes to reduce the impacts of floods, the strategy presupposes morphological conditions that seem highly unrealistic, not just in large parts of the Netherlands, but also in many other sediment starved coastal systems. Moreover, a delta without dikes would unlikely be able to provide protection against the low-probability, extreme events that the Dutch flood defences have to withstand. This is essentially an "early hit problem": an extreme event could strike before sedimentation has elevated the land. Finally, it seems questionable whether a strategy to leave deltaic regions untouched will often be compatible with population pressures and efforts to stimulate economic growth. (chapter 4)

9. The Dutch major hazards and flood safety policies show remarkable similarities. Yet the Dutch major hazard policy focuses strongly on loss of life, while the present-day flood safety policy does not. Loss of life and other intangible losses

are included in the financial balance of the cost-benefit studies that are used in the Netherlands to derive/rationalize flood safety standards. The value functions that are used are linear, while the FN-criteria that are used in the Dutch major hazards policy are averse to larger numbers of fatalities. If this inconsistency were to be removed by using non-linear (e.g. quadratic) value functions for fatalities, loss of life could come to dominate the outcomes of the cost-benefit-analyses for the Dutch flood defences. (chapter 5)

10. Cost-benefit analyses for the evaluation of HSE-policies in the Netherlands lack a strong common basis. For instance, loss of life and health are sometimes valued in money terms and included in the financial balance, but sometimes they are listed separately. One should therefore be careful to prioritize actions across policy domains on the basis of the reported financial balances alone. (chapter 6)

11. Societal risk criteria are related to efficiency (total output) rather than equity (individual exposures). While too stringent societal risk criteria would give rise to excessive social cost, too lenient criteria would allow the too frequent occurrence of large-scale accidents. Societal risk should primarily be evaluated at a national level as a large-scale accident at e.g. an LPG fuelling station is likely to cause fear about the safety of LPG fuelling stations in general. The societal risk criteria that are imposed on individual establishments should contribute to a level of risk that is considered acceptable from a national perspective. When the marginal costs of risk reduction differ from establishment to establishment, different societal risk criteria should be imposed on different establishments. Pressing for uniform societal risk criteria is to confuse equity and efficiency. (chapter 7)

12. "The" precautionary principle should not be used as a basis for risk decision making. Many interpretations of this ill-defined principle share two ingredients that may lead to results that are inconsistent with the ethic on which this thesis rests: (i) a bias towards prevention (or: a bias towards government intervention), and (ii) the use of taxonomies of risk for the selection of risk management strategies. Rather than to refer to "the" precautionary principle in public debates, it is proposed to debate, on a case by case basis, the conditions (such as the prospect for learning) that should influence decisions under uncertainty. (chapter 8)

13. Contrary to popular belief, the safety chain (proaction, prevention, preparation, repression, recovery) is not as weak as its weakest link: it is at least as strong as its strongest link. Underperforming links need not always be strengthened. A disproportional emphasis on disaster preparedness might lead to excessive investments in preparation, and divert scarce resources from links in the safety chain where these resources could have been put to greater use. (chapter 9)

14. The definition of an optimal level of disaster preparedness should encompass a probabilistic element. Using a welfare maximizing approach, the optimal level of preparedness can be defined as the optimal frequency with which response capacity is expected to fall short. This optimal frequency is (largely) independent of the probability distribution of demand so that regional differences will arise between optimal response capacities. Different levels of preparedness will also be appropriate for the different emergency services (medical aid, police, fire brigades). After all, there is little reason to assume that the costs and gains of improved preparedness will be the same for all emergency services. (chapter 9)

15. Concentration, moral hazard on the part of the government, and risk perception are important obstacles to the insurability of large-scale floods in the Netherlands. In the somewhat exceptional Dutch case, the issue of moral hazard concerns moral hazard on the part of the government (which is responsible for the flood defence system) rather than moral hazard on the part of individuals (individuals cannot escape taxation). An insurance arrangement in which the national government plays a dominant role and provides underwriting capacity would be a viable and efficient means to resolve the uninsurability of large-scale floods in the Netherlands. (chapter 10)

16. The interplay between risk transfer (e.g. insurance) and prevention should not be overlooked. It is incorrect to optimize failure rates on the basis of risk-neutral cost-benefit studies when the cost of risk bearing exceed expected loss. When full insurance against the actuarially fair premium is unavailable, the cost of risk bearing typically exceed expected loss. The Dutch use risk neutral cost-benefit analyses to derive or rationalize flood safety standards. As there is currently no (government) flood insurance program in the Netherlands, the assumption of risk neutrality does not (yet) seem justified. The introduction of a flood insurance program thus cannot be used as an excuse for not meeting flood safety standards (derived from risk neutral cost-benefit analyses) or as a justification for lower levels of protection. (chapter 11)

12.3 Recommendations for further research

Several themes have been touched upon that would be interesting to work out in greater detail. But in line with the utilitarian ethic on which this thesis rests, I believe scientific and social relevance to be insufficient conditions for further research. Research after all comes at a cost. The question is not whether further research would be relevant, but whether it would *sufficiently* relevant. I will therefore limit myself to three research opportunities that, in my view, would definitely be worth the effort.

1. Cost-benefit analyses that deal with health, safety and the environment seem to lack common ground. A guide, linked to the existing OEEI-guide for the appraisal of infrastructural projects, could improve the comparability and quality of such cost-benefit analyses. Greater comparability would allow decisions makers to use the outcomes of CBAs to prioritize actions across hazard domains.

2. Because large-scale floods in the Netherlands are not unthinkable, and because disaster assistance is likely to be haphazard and inefficient without clear rules and procedures, it would be sensible to draft a flood insurance program. While I have argued in chapter ten for the introduction of an arrangement in which the national government plays a dominant role, the details of such an arrangement have been left unaddressed. Many operational issues are yet to be explored.

3. The final recommendation for further research concerns the process of policy formulation. Numerous scholars have stressed that the way in which decision making is organized strongly influences the decisions that are eventually made (e.g. Klinke and Renn, 2002; Renn et al., 1993; Vlek, 1996; Gregory et al., 2001). Considerable changes seem to have taken place in the ways in which experts and the public are involved in risk decision making. Contrasting similar cases within single policy domains, e.g. the Delta Works and the Space for the Rivers Project, could yield useful insights. While greater public participation and interest group corporatism are often said to improve the quality and legitimacy of public policy, deliberative democrats have raised awareness for the quality of public debate (e.g. Delli Carpini et al., 2004). It would be insightful to evaluate to what extent trends in the process of policy formulation fit a move towards (or from) a deliberative democracy, bearing in mind that a participatory democracy is not necessarily the only or best institutionalization of a deliberative democracy (Held, 1996).

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Appendix I

Defining hazards, safety and risk

A **hazard** is defined by the UK's Health and Safety Executive as '"the potential for harm arising from an intrinsic property or disposition of something to cause detriment" (HSE, 2001: 2). Vrouwenvelder et al. (2001) defined a hazard as "a set of conditions that may lead to undesirable or adverse effects". The definition of a hazard adopted here is the one proposed by ISO/IEC Guide 51 (1999): a hazard is a "potential source of harm". The common element in all definitions is the presence of something that may cause **harm**. The definition of harm adopted here is the one proposed in ISO/IEC Guide 51: harm is "physical injury or damage to the health of people, or damage to the property or the environment" (ISO IEC, 1999: 2).

Safety is defined by Vrouwenvelder et al. (2001) as "a state of being adequately protected against hurt or injury, free from serious danger or hazard". Throughout this thesis, the term safety is used to refer to the degree of being free from risk. Note that safety and risk are inversely related according to this definition: a high level of safety implies a low level of risk.

The definition of **risk** has considerable implications for the outcomes of decision-making: it frames a risk problem and influences the ranking of alternative solutions. "Defining risk is thus an exercise in power" (Slovic, 1999: 699). Risk is defined by the (HSE, 2001: 6) as "the chance that someone or something that is valued will be adversely affected in a stipulated way by the hazard". Numerous definitions of risk are in use. Vlek (1996) has compiled a list of eleven formal definitions of risk (Table 12). All definitions revolve around probabilities and consequences. In engineering, risks are commonly defined as a function of probabilities and consequences. That definition has been used throughout this thesis.

Probabilities can be interpreted in various ways (see e.g. Bedford and Cooke, 2001 for a more detailed discussion). A frequentist interprets a probability as the relative frequency of the outcomes of an infinite number of identical experiments. But because risk analysts typically have to deal with unique, non-repetitive events, a different interpretation is widely used in quantitative risk analyses (Apostolakis, 1990; Kaplan and Garrick, 1981). Under a **subjective** or **personal interpretation**, a probability is a degree of belief in the truth of a given proposition (such as the proposition that a flood will occur next year) (Savage, 1974). It is this interpretation that is used throughout this dissertation. Personal probabilities do not have to be same across individuals, and they could change dramatically in the light of new information.

Table 12
Formal definitions of risk (Vlek, 1996: 12)

1	Probability of unintended consequence
2	Seriousness of (maximum) possible undesired consequence
3	Multi-attribute weighted sum of components of possible undesired consequences
4	Probability x seriousness of undesired consequence ("expected loss")
5	Probability-weighted sum of all possible undesired consequences ("average expected loss")
6	Fitted function through graph of points relating probability extent of undesired consequences
7	Semi variance of possible undesired consequences about their average
8	Variance of all possible consequences about mean expected consequence
9	Weighted sum of expected value and variance of all possible consequences
10	Weighted combination of various parameters of the probability distribution of all possible consequences (encompasses 8 and 9)
11	Weight of possible undesired consequences ("loss") relative to comparable possible desired consequences ("gain")

Risk perceptions are the mental images of the severity of risks (Slovic, 1987). Two distinct approaches have been developed to explain risk perceptions. Cultural theory explains risk perceptions by social stimuli and personal experiences, whereas the psychometric paradigm explains risk perceptions by risk characteristics (Kraus and Slovic, 1988). The results of studies by Marris et al. (1998) and Sjöberg (2000) show that the psychometric paradigm explains a greater proportion of the variance in risk perceptions than cultural theory. Yet even the explanatory value of the psychometric model is rather limited when it comes to individual rather than population averaged results (Marris et al., 1998; Sjöberg, 2000).

Appendix II

The risk management process

While there is no single definition of "the" risk management process, considerable agreement exists on its various elements: the specification of objectives, hazard identification, risk estimation, risk evaluation, risk reduction and risk control (e.g. Ale, 2002; Bohnenblust and Slovic, 1998; CUR190, 1997; Vrouwenvelder, 2001; Rosenthal et al., 2002; ISO IEC, 1999; Vlek, 1996). Figure 31 gives a schematic overview of the relations between these stages. Risk analysis concerns the definition of objectives, hazard identification and risk estimation. Risk assessment also comprises risk evaluation (after ISO IEC, 1999).

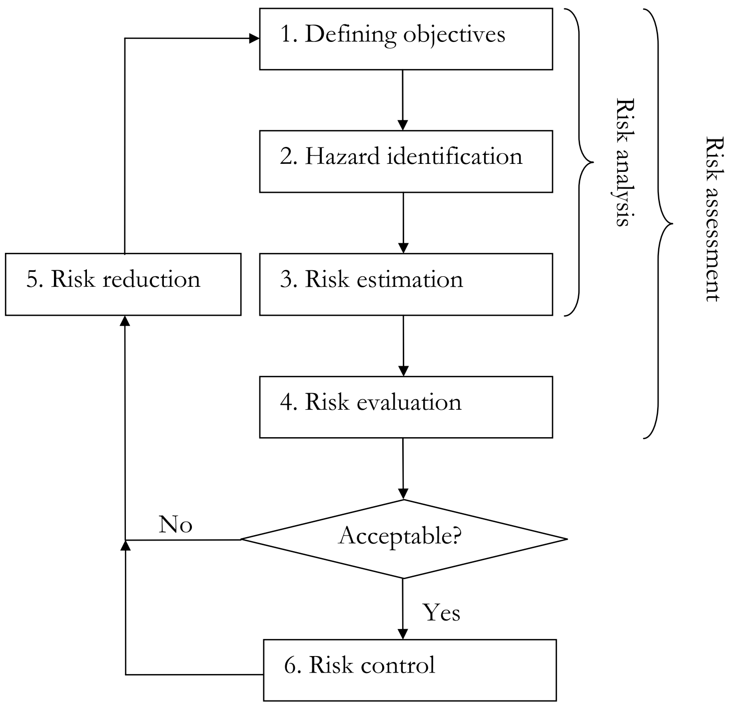

Figure 31 The iterative risk management process (adapted from ISO IEC, 1999)

Risk regulation can concentrate on one or more phases of the risk management process. Regulators often prescribe risk reduction measures. They sometimes leave open how risks should be reduced. Regulations then focus on risk evaluation by defining levels of (un)acceptable risk. In that case, regulators often also prescribe risk estimation methods and methods for hazard identification as these strongly influence risk estimates.

ad 1. Defining objectives

Defining the key objectives of an organization or technological system is an important first step of a risk assessment.. The remainder of the risk management process focuses on those functions that are deemed critical for meeting the selected objectives.

ad 2. Hazard identification

Hazard identification involves the systematic search for hazards and associated accident scenarios. The hazard identification step is of critical importance as only identified hazards and accident scenarios can be dealt with. Numerous techniques have been developed for the identification of hazards and corresponding scenarios (Table 13).

ad 3. Risk estimation

Risk estimation comprises the estimation of the probability and severity of harm. One could debate the probability of harm in a relative sense ("x is more probable than y"), or in an absolute sense ("the probability of x is such and so"). The latter can be done quantitatively or qualitatively ("negligible", "low", etc.). Quantitative risk assessments are often time consuming and costly, while the uncertainties surrounding the outcomes can be considerable. Benchmark exercises typically show that the outcomes of the quantitative models that are used in the field of industrial safety vary over orders of magnitude (e.g. Ale, 2001; Amendola et al., 1992; Risø, 2002). [68] But while QRA undoubtedly has its flaws, one should be careful to throw out the baby with the bathwater. When confronted with uncertainty, people often rely on heuristics that give rise to several biases (Kahneman and Tversky, 1974). This becomes particularly acute when it comes to low-probability events. Probability neglect (see e.g. Kunreuther and Pauly, 2004; Sunnstein, 2003) could have disastrous consequences when it comes to potentially catastrophic events such as nuclear meltdowns and large-scale floods. For complex, highly reliable systems, quantitative risk assessments can help identify dominant failure modes and provide value engineering insights (see also Apostolakis, 2004).

[68] When QRA-outcomes are used as a basis for risk decision making (as in the Dutch major hazards policy), robust methods are needed to prevent arbitrary rule. Unfortunately, the validity and robustness of risk modelling techniques often conflict (see also Uijt de Haag et al., 2008).

Table 13
Hazard identification techniques

Brainstorming/HAZID	An expert panel creates a list of hazards through a creative process (Crawley and Tyler, 2003).
Incident data banks/ hazard checklists	The use of accident/incident statistics or historical records to identify hazards (Faber and Stewart, 2003; Crawley and Tyler, 2003).
Preliminary Hazard Analysis (PHA)	PHA involves the systematic search for major hazards and their causes, and the estimation of the severity of potential consequences. The analysis is often aided by a list of potentially hazardous elements (Stewart and Melchers, 1997; Crawley and Tyler, 2003).
Failure Mode and Effect Analysis (FMEA)	FMEA involves the systematic identification of component failure modes. The probabilities and consequences of component failures are estimated qualitatively and structured in tabular form (CUR190, 1997; Crawley and Tyler, 2003).
Failure Mode, Effect and Criticality Analysis (FMECA)	FMECA is an FMEA with a criticality matrix. Risks are ranked in order of severity (CUR190, 1997; Crawley and Tyler, 2003)
Hazard and Operability Study (HAZOP)	A preferably interdisciplinary team systematically checks the effects of deviations from design conditions using guide words such as 'less' and 'more' (Pasman, 2000; Crawley and Tyler, 2003).
Fault Tree Analysis (FTA)	A fault tree shows the relations between events that could lead to a critical event (CUR190, 1997).
Event Tree Analysis (ETA)	An event tree shows the relations between the potential consequences of a critical event (CUR190, 1997).
Bow-tie	A bow-tie combines a fault tree and an event tree.
Layer of Protection Analysis (LOPA)	Analysts try to identify independent layers of protection while focusing on a single scenario (Pasman, 2000; Crawley and Tyler, 2003).

ad 4. Risk evaluation

Risk decision making could, amongst other, be informed by (or based on) expert judgment, public deliberation, cost-benefit analysis, or risk-risk comparison (e.g. Fischhoff et al., 1981). To facilitate the appraisal of risks in a large number of broadly similar cases, decision makers could lay down relatively simple decision making rules to avoid having to evaluate risks on a case-by-case basis. A risk matrix is a practical tool that directs attention to those risks that are significant (Pasman, 2000). A key difference between an FN-criterion and a risk matrix is that the first considers the entire (cumulative) loss distribution whereas the latter only considers single events.

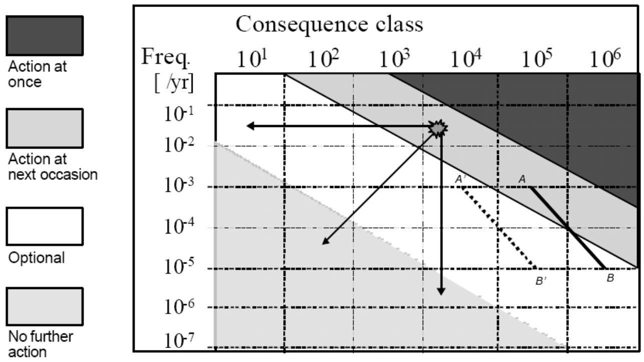

Figure 32 A risk matrix (Schupp et al., 2002)

There is often a grey area between risks that are considered "broadly acceptable", and those that are considered "broadly unacceptable". Such a grey area can for instance be found in the UK’s major hazards policy that discerns between "tolerable" and "acceptable" risks (HSE, 1988; 2001; 2004). While ALARP has to be demonstrated for risks that are "tolerable", risks that are "broadly acceptable" are subjected to a less stringent regime. Tolerability and acceptability are essentially two points on a sliding scale.

ad. 5 Risk reduction

When a risk is not yet considered acceptable we could abandon the (potentially) hazardous activity, or we could reduce and/or transfer[69] the risk. Securities and insurance markets provide important mechanisms for risk transfer.

ad. 6 Risk control

New insights should constantly be fed back into the risk management process. Scientific progress and practical experience may lead to the discovery of previously unknown risks, improved risk estimates, and/or better ways to mitigate risks. Risk management is a cyclical process.

[69] More accurately: we could transfer the burden of potential consequences.

Appendix III

Deaths and injuries

There are numerous rules of thumb that predict the potential number of injuries in an accident by the potential number of fatalities. The Leidraad Maatramp (SAVE and AVD, 2000), a Dutch guideline for assessing regional standards of disaster preparedness, also assumes a more or less proportional increase in the number of injuries when the number of fatalities increases. In this appendix, the hypothesis will be put to the test that the number of injuries is typically greater in accidents with higher numbers of fatalities than in accidents with lower numbers of fatalities.

Data

The Emergency Events Database[70] contains quantitative data of over 12800 mass disasters from all over the world from 1900 to the present. The database is maintained by the WHO Collaborating Centre for Research on the Epidemiology of Disasters (CRED). Its sources include UN agencies, NGOs, insurers, research institutes, and press agencies. The database differentiates between three disaster categories: natural disasters, technological disasters and complex disasters. For the purposes of this study, only industrial accidents and transport accidents were selected.

An event is entered into the database when it meets at least one of the following criteria: 10 or more people reported killed, 100 people reported affected, a declaration of a state of emergency, or a call for international assistance. The number of people reported killed is the number of persons confirmed dead plus the number of persons that is missing and presumed dead. The database contains official figures when available. The number of people affected is the number of people requiring immediate assistance during an emergency and also includes displaced or evacuated people. One has to be careful when interpreting the data stored in the database as figures might be inaccurate or unreliable. The procedures for data collection and reporting vary considerably across regions and time. Deliberate misreporting for political reasons cannot be ruled out.

[70] EM-DAT: The OFDA/CRED International Disaster Database - www.em-dat.net - Université Catholique de Louvain - Brussels - Belgium.

Deaths and injuries in industrial accidents
The industrial accidents reported in the EM-DAT database were selected that occurred in the period 1960-2004 in the 2005 EU-member states.[71] Poisoning, a disaster subset, was removed from the dataset.[72] Of the remaining 74 industrial accidents, fatalities were reported in 27 cases, injuries were also reported in 27 cases (Figure 33).

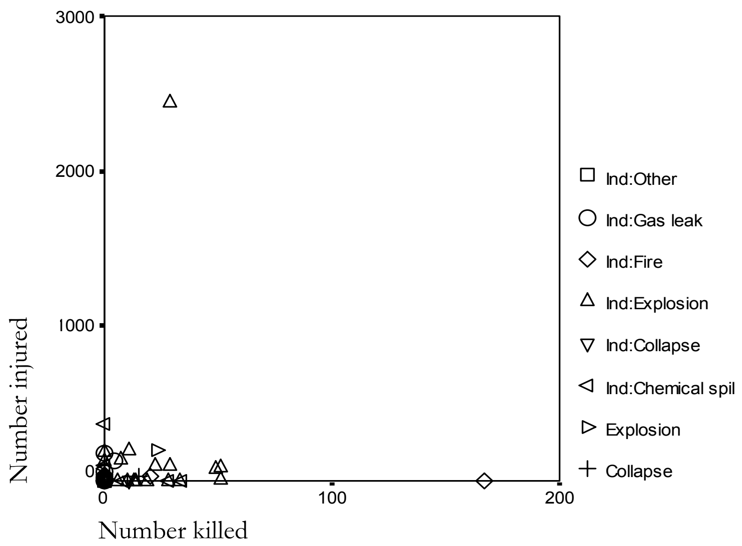

Figure 33 Scatter plot of number of killed and injured persons in industrial accidents (data: EM-DAT)

One of the outliers is the Toulouse disaster of 2001 in France, an explosion that caused 29 fatalities and 2442 injuries. The other outlier is the Piper Alpha disaster of 1988 that caused the death of 167 persons (no injuries reported). When these outliers are omitted from the dataset, the following, more insightful figure is obtained:

[71] Accidents in Austria, Belgium, Denmark, France, Germany, Greece, Hungary, Ireland, Italy, Netherlands, Poland, Slovakia, Slovenia, Spain, Sweden, United Kingdom.
[72] A notable poisoning accident is the 1981 disaster in Madrid, Spain, that caused 340 deaths and 20.000 injuries when oil intended for industrial purposes was sold as olive oil.

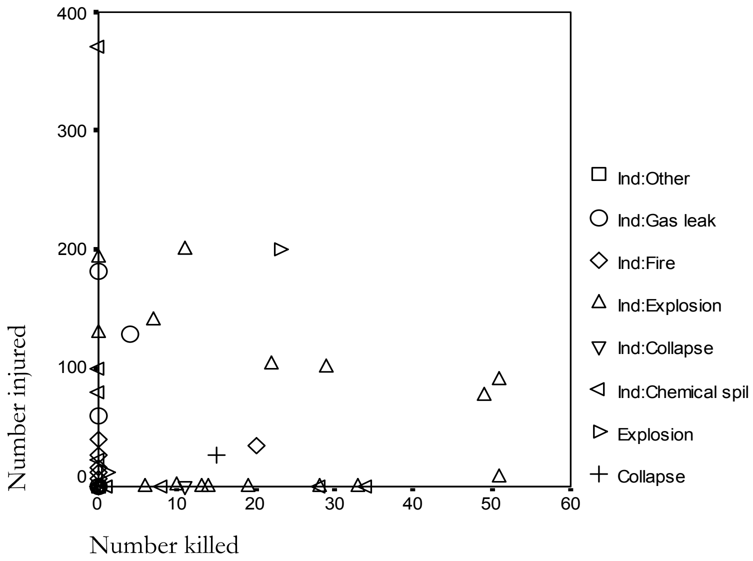

Figure 34 Scatter plot of number of killed and injured persons in industrial accidents, excluding Toulouse and Piper Alpha (data: EM-DAT)

As is already apparent from these graphs, correlations between deaths and injuries are low and insignificant (see also Table 14). The hypothesis has to be rejected for all disaster subsets: the number of injuries in accidents with higher numbers of fatalities is not typically greater than in accidents with lower numbers of fatalities.

Table 14
Number of deaths and injuries per accident category without Toulouse and Piper Alpha (none of the correlations is statistically significant)

Disaster subset	Number of accidents	Correlation coefficient	Average number of injuries	Average number of deaths	Overall ratio
Collapse	1	-	27	15	1.8
Explosion	2	-	106	12	8.8
Chemical spill	21	-0.126	27.2	3.4	7.9
Ind:Collapse	1	-	0	11	0
Ind:Explosion	20	-0.031	52.1	17.2	3.0
Ind:Fire	22	0.516	6.1	0.9	6.8
Ind:Gas leak	4	0.304	92.8	1	92.8
Ind:Other	1	-	0	0	-

A statistical analysis by TNO (unpubl.) of incidents reported in their FACTS-database yielded similar results. A study by Rushton and Glossop (2005) did however find weak positive correlations between deaths and injuries for various accident categories. Their results were based on a statistical analysis of the incidents reported in Lees (1996: Appendix I) that caused at least one fatality. This selection criterion is however likely to have influenced these correlations.

Deaths and injuries in transport accidents
Transport accidents were selected from the EM-DAT database that occurred in the period 1990-2004 in France, Germany, Belgium, Italy, Luxembourg, the Netherlands, Denmark, Ireland, United Kingdom, Greece and Portugal. Of the 95 selected transport accidents, deaths were reported in 91 cases, injuries in 49.

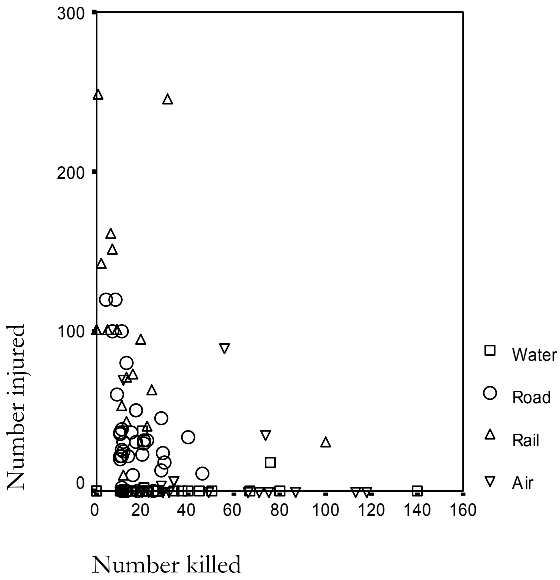

Figure 35 Scatter plot of number of killed and injured persons in transport accidents (data: EM-DAT)

As is already obvious from Figure 35, injuries and deaths are poorly correlated. For all subsets (water, road, rail and air) the hypothesis has to be rejected that the number of injuries is typically greater in accidents with higher numbers of fatalities than in accidents with lower numbers of fatalities.

A possible explanation for the observed relation between deaths and injuries

Correlations between individual doses and responses influence the numbers of deaths and injuries per accident. Consider for instance a number of accidents (n), each affecting N_a individuals. An affected individual is killed, wounded or left unharmed. Let us assume that individual doses (d_i) and resistances (r_i) are randomly distributed over affected populations. Assume that an individual is wounded when his or her dose exceeds 50% of resistance ($d_i>0.5r_i$), and that an individual is killed when his or her dose exceeds resistance ($d_i>r_i$). The distribution of individual doses has been modelled by an exponential distribution because it seems increasingly less likely that an affected person receives a higher dose. The distribution of resistances has been modelled by a (symmetric) normal distribution. Depending on the correlations between individual doses as well as resistances, we could observe the following patterns (Figure 36).

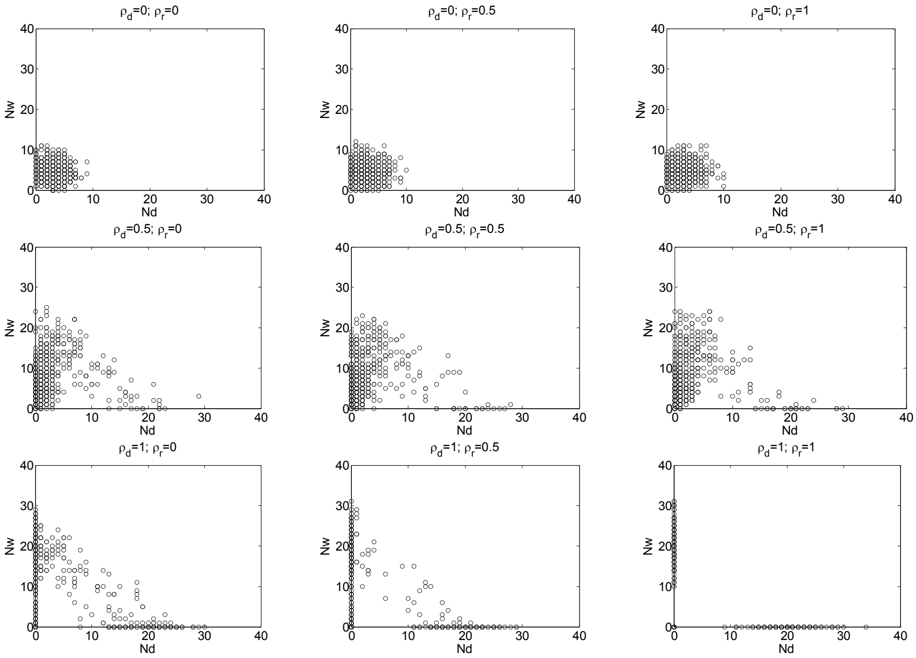

Figure 36 Deaths (Nd) and injuries (Nw) for different correlations between individual loads (ϱ_d) and resistances (ϱ_r). Input: n=1000; d~Exp(5); N_a~Bin(100,0.2); r~Norm(10,1).

The scatter plots in the middle and bottom rows of Figure 36 show considerable resemblance to actual accident statistics (Figure 34 and Figure 35). Strong correlations between individual doses are to be expected in transport accidents: a plane crash for instance affects all passengers in a broadly similar way. Strong correlations between individual resistances are to be expected when affected populations are relatively homogeneous (consider for instance a transport accident that only involves elderly passengers).

Appendix IV

A loss distribution for large-scale floods

This appendix presents the results of a preliminary study of the loss distribution for floods caused by the failure of primary flood defences.[73] Although these results are subjected to considerable uncertainties, they offer insights into orders of magnitude that are important for the design of an insurance arrangement. Could potential losses for instance exceed the underwriting capacity of the Dutch insurance industry? And would a 1 billion euro reinsurance layer cover a meaningful fraction of potential loss? These and other questions cannot be addressed without insight into potential losses and their probabilities.

Combining scenario estimates into an overall loss distribution
The definition of risk as a set of triplets, proposed by Kaplan and Garrick (1981), provides a useful starting point for the derivation of a distribution of expected annual losses from the probabilities and consequences of individual flood scenarios:

$$\mathrm{R} = \left\{ \left\langle s_i, p_i, q_i \right\rangle \right\}$$

Where R = risk; s_i = scenario i; p_i = probability of scenario i; q_i = consequences of scenario i.

A flood scenario could be "the breach of a primary flood defence ". This scenario could in turn be subdivided into other, smaller scenarios. A storm surge at sea could for instance cause numerous breaches of the primary flood defences, leading to floods in various parts of the country. This could be interpreted as a single scenario. But each of the breaches and subsequent floods could be interpreted as a scenario as well. Although the definition of a scenario might therefore seem arbitrary, the all-important rule is that scenarios should be mutually exclusive, at whatever level of aggregation, to avoid the double-counting of their consequences.

A flood scenario is triggered when the protection scheme that prevents it fails to withstand its load. The probability of a scenario thus equals the failure probability of its protection scheme, which could be a levee, a dam, or a dune. A protection scheme fails when an event, such as a storm surge or extreme river discharge, creates a load that exceeds the resistance or strength of the protection scheme. Both resistances and loads are typically uncertain. Although the resistance of, say, a dike section could theoretically be perfectly assessed, lack of soil data and model uncertainties imply that there are often

[73] The results presented here are part of an article prepared with W. Kanning and Dr. M. Kok.

considerable uncertainties related to the resistances of individual dike sections. The failure probability of a protection scheme is thus determined by the probability density functions of its load and resistance/strength:

$$P_{fi} = P_i(S_i \geq R_i) = \int_{-\infty}^{\infty}\int_{-\infty}^{S} f_{R_i,S_i}(R_i, S_i) dR_i dS_i$$

Where P_{fi} = failure probability of protection scheme *i*; R_i = resistance; S_i = load; $f_{Ri,Si}$ = joint probability density function of resistance and load.

When the loads as well as resistances of individual protection schemes are independent, it is highly unlikely that they will all fail simultaneously. But when loads as well as resistances are fully correlated, all schemes will always fail simultaneously (when they fail), triggering all scenarios at the same time. Consider for instance a number of flood scenarios (i=1..n) with probabilities p_1, p_2,..., p_n and consequences q_1, q_2,..., q_n. A flood scenario is triggered by the failure of its protection scheme. Figure 37 shows two loss distributions for two distinct cases. In the first case, loads as well as resistances are uncorrelated ($\varrho_{Ri,Rj}$=0 and $\varrho_{Si,Sj}$=0 for all $i \neq j$). In the second case, loads as well as resistances are fully correlated ($\varrho_{Ri,Rj}$=1 and $\varrho_{Si,Sj}$=1 for all $i \neq j$). While expected loss is the same in both cases, downside risk is considerably larger in the second case. For insurers that are particularly concerned about large downsides, knowledge about correlations is thus highly relevant.

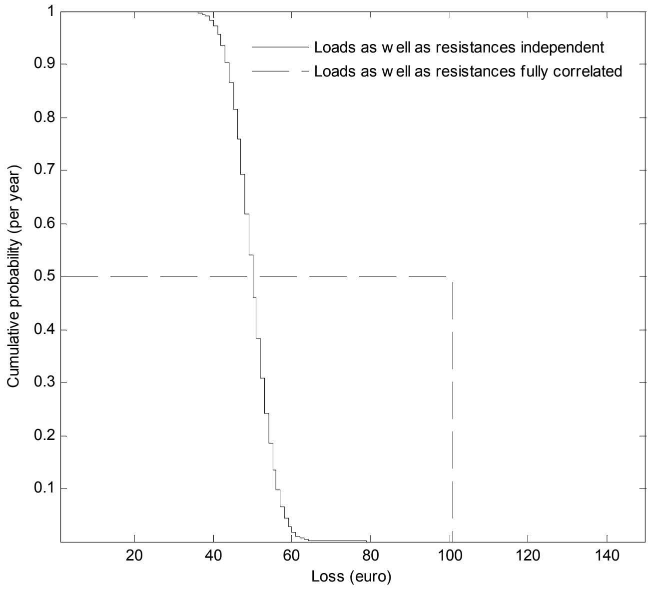

Figure 37 Loss distributions for a situation in which loads as well as resistances are fully correlated, and a situation in which loads as well as resistances are independent for n=100; p_i=0.5 (i=1..n) per year; q_i=1 euro (i=1..n)

The resistances of flood protection schemes are usually largely uncorrelated. But strong correlations between loads are often to be expected. After all, storm surges and extreme river discharges typically affect vast areas. During the 1953 flood, the Dutch sea defences were breached at about 150 locations (Gerritsen, 2005). And the storm surge that struck New Orleans in 2005 caused over 20 breaches of the city's flood defences (IPET, 2006).

Deriving a loss distribution for floods caused by the failure of primary flood defences

Loss distributions for floods caused by the failure of primary flood defences cannot be derived from loss statistics directly given their low-probability nature. Quantitative risk modeling techniques and engineering judgment thus have to be relied upon. To estimate risks, state of the art modeling techniques combine (i) estimates of the hydraulic conditions during extreme events, (ii) estimates of the variables that determine the resistances of a flood defence system, and (iii) flood propagation models, land-use data and loss functions (e.g. Van Manen and Brinkhuis, 2005).

In 2001, the Netherlands Ministry of Public Works and Water Management commenced a study to gain insight into the probabilities and consequences of floods caused by the failure of primary flood defences. The multimillion euro FLORIS-project (Flood Risks and Safety in the Netherlands) aims at quantifying flood probabilities and consequences per dike ring using state of the art modeling techniques. The outcomes of the FLORIS-project would provide the ideal basis for the estimation of a national loss distribution. But so far, probability and consequence estimates are only available for 16 dike rings (Ministry of Transport Public Works and Water Management, 2005). The results of a preliminary study by Klijn et al. (2004) that covers all 53 dike rings were therefore used here. The probability estimates by Klijn et al. (2004) are based on less advanced modeling techniques than the ones used in the FLORIS-project and rely heavily on expert judgment. Needless to say, these data (and hence our results) are subjected to considerable uncertainties. Yet the main purpose of this Appendix is not to be exact but to provide insight into the severity of potential losses and the effect of dependencies on the overall loss distribution.

Figure 38 shows the consistency between the probability and consequence estimates by Klijn et al. (2004) and the results of the FLORIS-project. The flood probabilities reported in Klijn et al. (2004) appear consistently lower than the results of the FLORIS-project. At least for many river dikes, this can be (partly) attributed to piping, an important failure mode whose probability proved difficult to quantify. The computed piping probabilities (>0.01 per year for some dike rings) seem unrealistic, and research is currently being carried out to improve the piping module. It should be noted that the 0.01 annual flood probabilities reported in the FLORIS-report and shown in figure 5 are upper limits rather than best estimates.

Unlike the probability estimates, the loss estimates reported in Klijn et al. (2004) appear to be in reasonable agreement with the results of the FLORIS-project. In the FLORIS-project, detailed loss estimates were made for only three dike rings: the Northeast Polder (dike ring 7; loss estimate (average): $1.9.10^9$ euro), Central Holland (dike ring 14; loss estimate (average): $5.8.10^9$ euro), and Land van Heusden/De Maaskant (dike ring 36; loss estimate (average): $3.7.10^9$ euro). These estimates were made using flood propagation models. For the other 13 dike rings, it was assumed that the entire dike ring would be flooded in case of flood. Especially for large dike rings along the sea and Lake IJssel, this is likely to overestimate damages as it is highly improbable that such dike rings will be completely flooded (Wouters, 2005). The loss estimates reported by Klijn et al. (2004) are based on a method that combines land-use data, loss functions for different types of land-uses, and estimates of inundation depths. Results of flood propagation simulations (inundation depths) were used when available.

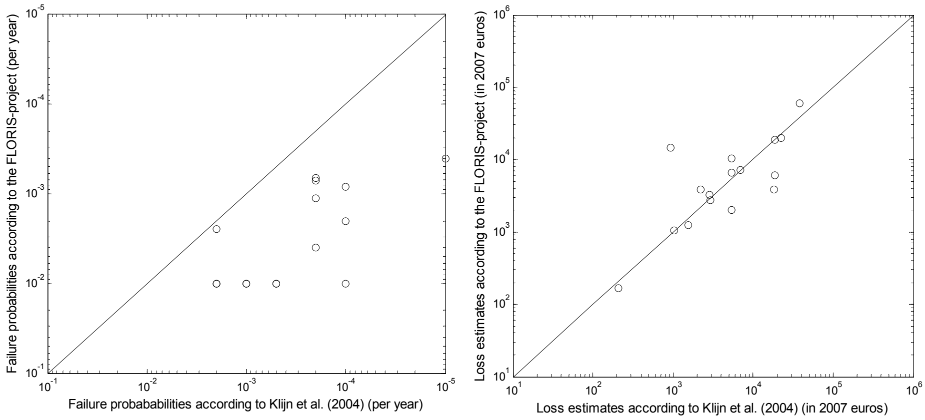

Figure 38 A comparison of the probability estimates (left-hand panel) and loss estimates (right-hand panel) according to Klijn et al. (2004) and the FLORIS-project (Ministry of Transport Public Works and Water Management, 2005)

When combining the flood probability and consequence estimates per dike ring into an overall loss distribution, one has to consider the effect of dependence. There are (roughly) six extreme events that could cause the simultaneous flooding of several dike rings: (i) a northern storm on the North Sea, (ii) a north western storm on the North Sea, (iii) a storm over Lake IJssel, (iv) an extreme Rhine discharge, (v) an extreme Meuse discharge, and (vi) an extreme river discharge combined with storm at sea (see also Kolen and Geerts, 2006) (Figure 39).

Different flood scenarios were defined for each critical event, ranging from a worst case scenario to a relatively low-consequence scenario. The worst case scenario involved floods in all dike rings under consideration. The probability of this worst case scenario was assumed to be ten times lower than the failure probability of the strongest dike ring. The less severe scenarios involved the failure of two or more dike rings (again with probabilities ten times lower than the failure probability of the strongest dike ring).[74]

[74] The procedure followed to estimate scenario probabilities is obviously course. The main purpose of this Appendix is however not to be exact but to provide insight into the severity of potential losses and the importance of dependencies.

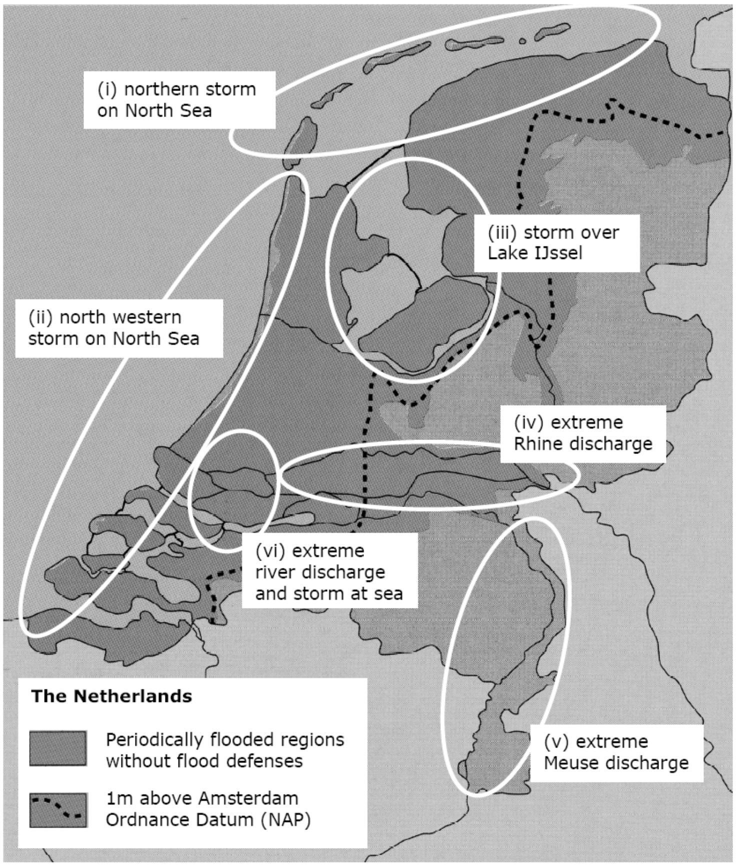

Figure 39 Events that could cause the simultaneous flooding over several dike rings

In defining the worst case scenarios, engineering judgment played an important role. For example, the probability of the Northeast polder (dike ring 7) and Flevoland (dike ring 8) both being flooded is extremely low given the storage capacity of these dike rings relative to the size of Lake IJssel. And when it comes to extreme Rhine discharges, a major flood upstream (e.g. in Germany) would reduce water levels downstream. A credible worst case river flood therefore mostly involves floods in the western and middle part of the country (with breaches starting in the west), rather than floods in dike rings 49-53 along the river IJssel (see also Kolen and Geerts, 2006).

Table 15 lists the probability and loss estimates for each scenario, as well as the identifiers (numbers) of the affected dike rings. Since we are only interested in those damages that could be insured (rather than the total economic impact of a flood), losses are defined as the direct private sector damages that are to be insured. In each case, it was assumed that these are 65% of total loss (based on the damage categories in HIS-SSM that could be insured).

Table 15
Events, scenarios, probabilities and loss estimates (losses that are to be insured only)

Event	Dike rings involved in flood scenario (see Figure 4)	Probability estimate (yr^{-1})	Loss estimate (10^9 euro)
1. Northern storm on North Sea	1, 2, 3, 4, 5, 6	1.10^{-5}	30.3
	1, 2, 3, 4	2.10^{-5}	0.4
2. North western storm on North Sea	8, 10, 11, 13, 14, 20, 25, 26, 28, 29, 30, 31, 32	1.10^{-6}	64.1
	8, 10, 11, 13, 20, 25, 26, 28, 29, 30, 31, 32	5.10^{-6}	52.0
	8, 10, 11, 20	2.10^{-5}	12.7
	10, 11, 20	5.10^{-5}	7.1
3. Storm over Lake IJssel	8, 45, 46	1.10^{-6}	9.7
	8, 46	4.10-5	4.8
4. Extreme Rhine discharge	16, 38, 40, 41, 42, 43, 48	1.10^{-5}	37.3
	16, 38, 40, 41, 42, 43	2.10^{-5}	32.8
	16, 40, 41, 43	2.10^{-4}	30.2
5. Extreme Meuse discharge	36, 38, 39, 41	2.10^{-5}	17.3
	36, 39, 41	1.10^{-4}	15.4
6. Extreme river discharge and storm at sea	15, 16, 17, 20, 21, 22, 23, 24, 34	1.10^{-6}	65.2
	15, 16, 20, 21, 22, 23, 24, 34	5.10^{-6}	37.7
	15, 16, 20, 22, 23, 24, 34	2.10^{-5}	35.6
	15, 16, 20, 22, 23, 24	5.10^{-5}	31.8
	15, 16, 20, 23, 24	1.10^{-4}	25.7
	16, 20, 23	2.10^{-4}	20.6

An overall loss distribution was computed by combining the probabilities and consequences for the scenarios listed in Table 15 (the dependent failures), and the flood probabilities and consequences for the individual dike rings (the independent failures). To avoid double counting, the probabilities of the independent failures were adjusted to account for the effect of dependence. The resulting loss distribution is shown in Figure 40. The limited number of scenarios causes the loss distribution to have a strongly discontinuous character, but it has little consequence for its overall shape. It should however be kept in mind that the data and procedures that underlie this distribution are subjected to considerable uncertainties.

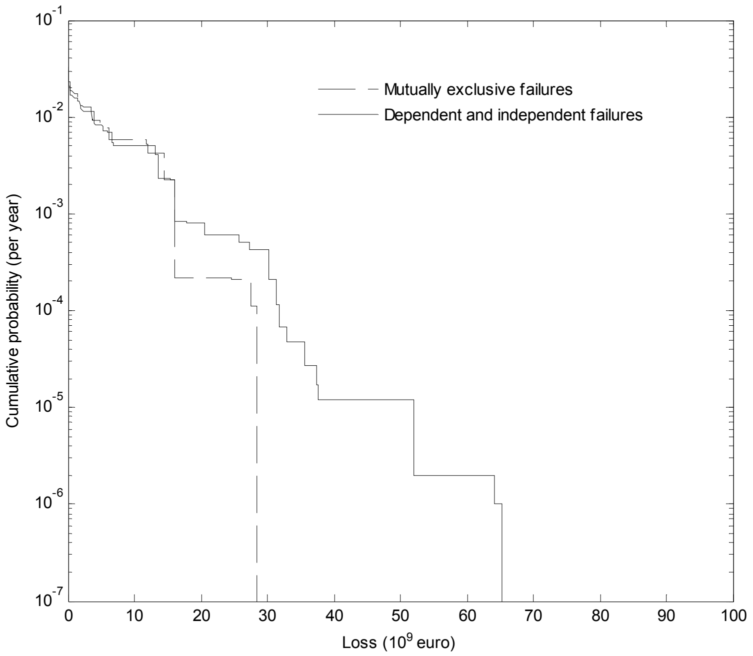

Figure 40 Loss distributions for floods caused by the failure of primary flood defences in the Netherlands (losses that are to be insured only), assuming that dike ring failures are mutually exclusive, or that multiple dike ring failures could be triggered by a single event

While losses in the tens of billions of euros would be relatively unlikely if the failure of one dike ring were to preclude the failure of another, they are much more likely when there are dependencies. Although the results shown in Figure 40 might seem unduly pessimistic, the upper limit of 65 billion euro is relatively low compared to the Worst Credible Flood (WCF) described by Kolen and Geerts (2006). The total economic impact of the WCF has been estimated at 121 billion euro. Assuming again that the direct, economic damages that are to be insured constitute about 65% of total loss, this yields a maximum of 79 billion euro. This exceeds our maximum loss estimate by 18%.

Appendix V

Securitization

Securitization refers to the use financial instruments to transfer risks to capital markets. While a loss of say 35 billion euro would be an unparalleled loss for the traditional (re)insurance industry, it would be business as usual for the global securities market (stocks and bonds) where daily fluctuations normally exceed this figure by far (Cummins et al., 1999; Froot et al., 1995). The main cat-securities are cat-bonds, cat-futures and cat-options. A brief introduction to these instruments is given below.

Cat-bonds

Cat-bonds are state contingent bonds. They are comparable to a seventeenth century marine insurance arrangement named bottomry (Jaffee and Russell, 1997). Under a contract of bottomry, ship owners got a loan that only had to be repaid (with interest) if their ship was to return safely. Otherwise, the loan would be forgiven. Cat bonds are essentially the modern version of these age-old contracts. So how does it work? An originator (e.g. an insurance company) establishes a special purpose vehicle (SPV). The SPV issues cat-bonds and uses the proceeds to purchase liquid, highly-rated assets. The originator pays the SPV the equivalent of an insurance premium. Because the SPV acts like a reinsurer, it is also named special purpose reinsurer. When a cat-bond is triggered, the SPV liquidates its assets and transfers the proceeds to the originator. The SPV in turn loses the obligation to pay interest to the bondholders (with principle protected or coupon at risk bonds), as well as the obligation to pay off the principal (with principle unprotected or principle at risk bonds). Because cat bonds provide the originator the capital needed to settle claims upfront, the originator does not have to worry about potential default of the counterparty (Cummins, 2008).

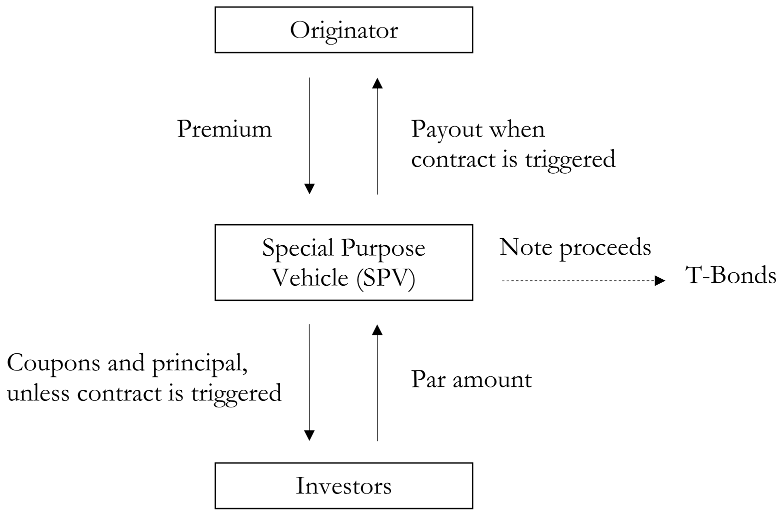

Figure 41 Schematic representation of the structure of a Cat-bond

There are various types of triggers in use (MMC Securities, 2005). Under an indemnity based trigger, payout is based on the loss suffered by the originator. Under an index based trigger, payout is based on the value of some index (reducing moral hazard but introducing basis risk). These indices can be parametric (e.g. based on the location and severity of an earthquake), based on industry-wide loss (e.g. the PCS-index), or based on modelled loss. A hybrid trigger is a composite trigger that involves two or more of the aforementioned triggers. The appropriateness of a trigger depends on the trade-off between moral hazard and basis risk. Indemnity based triggers protect their sponsors from basis risk but have the highest exposure to moral hazard. Index based triggers expose their sponsors to basis risk but have less exposure to moral hazard.

Cat-bonds are zero-beta assets that could offer investors diversification benefits and attractive returns (Froot et al., 1995; Litzenberger et al., 1996; Kielholz and Durrer, 1997). From 2001 to 2007, cat-bond premiums have gone down and they are now priced competitively with reinsurance for high layers of protection (Cummins, 2008). The total risk outstanding in the cat-bond market nearly doubled from \$4.90 billion in 2005 to \$8.48 billion in 2006 (MMC Securities, 2006). This strong increase has been explained by the unusual storm activity in the US in 2006 that depleted the insurance industry's capital stock (MMC Securities, 2006). Although it therefore remains to be seen whether this boom continues, the future for these securities as part of the catastrophe reinsurance market looks bright.

Catastrophe futures and options

In 1992, the Chicago Board of Trade introduced catastrophe futures and options (Hoyt and Williams, 1995). By purchasing cat-futures, an insurance company could hedge its exposure to large-scale losses: the value of the futures contract would rise if a catastrophe were to occur. Purchasing call options also offered protection against large-scale losses. A cat-option is very similar to an XOL-reinsurance contract (except for the underlying: not the insurer's loss experience but that of the industry). The cat-futures and cat-options were written on an industry-wide loss index to limit moral hazard. This, however, introduced basis risk: the hedge would no longer be perfect unless the insurer's portfolio would correlate perfectly with the index (Doherty, 2000).

Despite the opportunities that the CBOT futures and options seemed to offer, their trading volumes remained low. Reasons that have been put forward in literature include insurers' lack of expertise with futures, concern over possible default of the clearing house, uncertainty over regulatory constraints, and tax issues (D'Arcy and France, 1992). Moreover, regional insurers that held portfolios that were not strongly correlated with the index gained little by purchasing cat-futures (basis risk), and there were no obvious natural counterparts in these futures transactions: there seem to be few, if any, non-malicious investors or companies that would wish to hedge against unexpected low losses by selling futures contracts (Hoyt and Williams, 1995).

The CBOT stopped trading cat-futures and options in 1996 and 1999 respectively. In 2007, the New York Mercantile Exchange (NYMEX) introduced cat-futures and options again. The futures and options are written on an index that is based on data from the Property Claims Services (all natural peril property damages exceeding 25 million USD apart from those caused by earthquakes). Because floods in the Netherlands are uncorrelated with a US loss-index, the NYMEX cat-options and cat-futures are of no relevance to the insurance of flood risks in the Netherlands.

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- Professor Ben Ale (Delft University of Technology, safety science)
- Professor Hans Pasman (Delft University of Technology, industry & environmental protection, multi-scale physics)
- Pieter van Gelder (associate professor, Delft University of Technology)
- Marco Schraver (senior administrator, External Safety Directorate)
- André Griffioen (senior administrator, Crisis Management Directorate)
- Bas Jonkman (lecturer, Delft University of Technology; reliability engineer, Royal Haskoning)
- Jos Wessels (Netherlands Organization for Applied Scientific Research, TNO; chairman of the Dutch Association of Risk and Reliability, NVRB)
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Short curriculum vitae

Rudolf Bernard (Ruben) Jongejan was born on July 19, 1980 in Woerden, the Netherlands. After graduating from Minkema College Woerden in 1998, he went to Delft University of Technology to study Civil Engineering. In 2004, he graduated with honours at the section of Hydraulic Engineering and Probabilistic Design. The MSc-thesis was awarded the Study Award 2004 of the Dutch Association of Risk and Reliability (NVRB) and the Dutch Association for Risk Management (GvR). After graduation, he started as a PhD-student at Delft University. Besides being involved in various extracurricular activities, he studied Public Administration from 2001-2002 at Leiden University. He received his propedeuse (first year) in 2002 and then took up Political Science in 2003. Ruben graduated with distinction as a Bachelor of Arts in 2006. He did the Master's programme in The Hague and graduated with distinction in 2007. He followed several courses of the Econometrics programme at the Erasmus University of Rotterdam in 2006-2007, and worked as a visiting academic at the London School of Economics from May to September 2007. Ruben also served on two committees of the Netherlands Hazardous Substances Council, and he worked as a consultant in the field of reliability engineering and risk management. In 2008, he founded Jongejan Risk Management Consulting. Above all, he was the proud captain of Delft University's sociable hockey team.