SEVENTH FRAMEWORK PROGRAMME: THEME 7 TRANSPORT

OPTIC

Optimal Policies for Transport in Combination

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Deliverable 3

Ex-post identification and remedies of adverse effects

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Abstract

Policymakers are often required to make decisions in the face of risk and uncertainty. The information upon which they base their judgements may be insufficient, and the decision-support tools used may be limited in their scope or power (cf. Deliverable 2). The principle focus of Deliverable 3 is thus concerned with how issues of risk and uncertainty can be integrated into the planning process, both *ex-ante* and *ex-post*. A range of issues directly relevant to European policy-making are addressed, especially in the context of medium and long-term policies concerning infrastructure investment, environmental impacts, alternative fuels and vehicle technologies. These include: causes of risk, uncertainty and unintended effects; the salience of irreversibility, path dependency and lock-in effects; and the need for comprehensive *ex-post* monitoring and 'adaptive' planning processes which together facilitate targeted remedial action. The institutional challenges inherent in such an approach are also discussed.

Executive Summary

Risks and uncertainties are highly pertinent to policy making in the transport sector, particularly at an EU level, where an extraordinarily diverse array of technologies, markets and political, institutional, ideological, socioeconomic and behavioural contexts are involved. Policymakers in the transport sector are routinely required to make decisions in the face of risk and uncertainty. Most evidently, this can stem from a lack of information concerning particular transport problems, the inability of existing modelling tools to accurately cover the range of variables and causal relationships involved and the difficulties inherent in nature of contemporary policy processes themselves. This deliverable emphasises the complex, socio-technical nature of the contemporary European transport system and notes its vulnerability to conditions of irreversibility, path-dependency and lock-in effects.

The focus of this deliverable is on how concepts of risk and uncertainty might be integrated into the planning process, *ex-ante* and *ex-post*. Clearly, predicting unintended effects *ex-ante* and/or detecting unintended effects *ex-post* can only lead to improved policy-making if policy-making processes are sufficiently flexible and adaptable. This has profound implications for those following traditional approaches to decision making which assume a linear, deterministic model of reality. This deliverable thus extends the examination of risk and uncertainty in Deliverable 1—which was concerned with the transport system *per se*—to the policy-making process itself. It contests the assumption that model parameters are stable over time and asserts that, with uncertainty and irreversibility, there may be a degree of leeway present with respect to policy intensity and timing. The implications for policy design and methodologies available for the integration of risk and uncertainty in the design of policy *ex-ante* are briefly described.

Following economic theory, it is argued that instances of path-dependency may be explained through the concept of increasing returns. Some important causes of increasing returns in the transport domain are reviewed. It is contended, however, that conventional economic approaches fail to adequately address the integration of risk and uncertainty into optimal policy design and cannot easily offer solutions to undesirable situations of deep systemic ‘lock-in’. Specifically, three key policy areas in the EU and national transport sectors, where uncertainties and irreversibility are considerable, are briefly reviewed.

The deliverable also addresses how analysts might address policy limitations through *ex-post* monitoring and remedial action. In terms of monitoring, several main approaches and tools were distinguished, arranged according to a continuum of suitability for *ex-post* packaging and subsequent remedial action. In terms of *ex-post* remedial actions, it is important to recognise that this deliverable makes no attempt to offer categorical solutions to situation-specific ‘epistemic’ or ‘communicative’ limitations. Rather as ‘meta guidance’, its purpose is to offer an overarching framework which can inform analysts who, upon the realisation that a policy intervention is unsatisfactory, are tasked with ensuring that it *becomes* satisfactory. Clearly, such practical remedial actions will remain highly contingent

upon the specific problem context. The deliverable hence outlines what ostensibly represents an extension of the *ex-ante* guidance detailed in Deliverable 1, set in the context of the analysis undertaken in Deliverable 2.

This deliverable also addresses the inherent challenges of ensuring flexibility in planning and the institutional issues involved. Acknowledging that uncertainty and irreversibility and the propensity for unintended effects are endemic to contemporary transport problems, it recommends that policy makers follow 'adaptive' planning processes. A number of adaptive techniques such as: scenario planning, policy testing and the establishment of 'signposts' are recommended as suitable approaches.

Overall, this deliverable concludes that although transport systems are inherently characterised by significant risks and uncertainties, a variety of *ex-ante* and *ex-post* approaches are available to policy makers that may facilitate the development of effective and efficient policy interventions.

With the body of relevant knowledge gathered and built upon in this deliverable, and Deliverables 1 and 2, Work Package 4 will subsequently examine a series of 'best practice' examples of *ex-post* and *ex-ante* policy packaging approaches within the EU. In addition, Work Package 6 will draw on these deliverables in order to provide recommendations on optimal policy packages and factors influencing their transferability across national and regional boundaries.

1 Introduction

1.1 Background

The transport sector is often characterised as a socio-technical system or as an open complex system. The term socio-technical system is a conceptual reminder that technologies affect and are an effect of their broader infrastructural, organisational, regulatory, and symbolic environments. By open complex system we mean that there are multiple interacting markets, with many types of increasing returns and many positive feedback mechanisms between these markets, with many non-linear relationships and time lags and institutional settings as well as interactions with its surrounding markets and environment. Among the characteristics of such systems are path-dependency and lock-in effects.

Richardson (2005, p. 29) suggests that the complexity of the transport system "stems from the multiplicity of its hardware (infrastructure and vehicles) and of the people and organisations involved." The complexity is increased by the existence and "roles of different modes, regulatory and legislative bodies, service providers, builders, financing systems, technologies, land-use patterns and, most importantly, human behaviour". Kaijser (2005) looks at the complexities of an urban transport system and describes the short-term dynamics of the system in terms of its daily operation. He suggests that the long-term dynamics of an urban system is determined by the interplay of the many different systems that can influence the development of the transport system. Kaijser further suggests that an urban system itself has a "momentum", which he refers to as path dependency, a concept used by industrial economists. In many areas of human activities the choice of path at an early stage will strongly influence further developments. There are many cases where it is impossible to undo an early choice. They have an irreversible character. These frequently differ from what an "informed and benign" social planner would expect to find best.

From an economic perspective the complexity of the transport system has serious consequences. Most economic thinking uses simplifications and models to understand the world. These models will capture the essence of the process and help us understand it, but in doing so things are left out. This does not need to be a serious issue, but it can be. The alternative to this simplification is a set of very complicated dynamic models with many variables and different lags. This in turn might easily become a black box limiting, rather than helping our understanding of the processes involved. In other words, transport systems are difficult to model precisely. This is not only linked to the internal complexity of the system, but also to external factors, such as risk and spillover effects from other markets, feedback effects with different lags *etc*.

Furthermore, public interest in transport policies is in general very strong since all citizens are somehow involved in or affected by transport directly or indirectly. All different groups in society, for instance industry associations, hauliers, ecological interest groups, trade unions, retail business, groups with special needs, parents, students or retired people like to see their interests represented in transport policymaking. Decisions which are essential for solving transport problems are impaired by conflicting group interests, incompatible ideological stances and often mistakes are made in the assessment of public opinion. Even with an agreement about objectives it is likely that there would be disagreement about strategies to achieve objectives.

Against this scenario, it is not possible to fully avoid the appearance of unintended effects due to policy interventions (see for example Gifford 1994, Mander, *et al*, 2007; van Asselt & Rotmans 2002). Transport policymaking requires an integrated view; it has to take into account various alternative options, their possible consequences for the transport system and beyond, and societal conditions for implementation (see Marchau, Walker & van Wee 2010; Walker, Rahman & Cave 2001).

Political interventions, as well as innovations, can lead to unintended, unknown, adverse or unexpected effects in complex socio-technical systems (see Grunwald, 2002 and 2009). In terms of technologies, currently two developments are of striking importance: first, alternative fuels and vehicle technologies and second, intelligent transport system (ITS) technologies. Both developments are partly established and partly emerging technologies; but it is visible that they imply significant changes to the transport system and it is likely that they will challenge conventional routines and habits in the transport sector, for example through an increased market penetration of electric vehicles or by a spread of intelligent infrastructures.

Governing the transport system also means mediating between various objectives such as economic development, environmental protection, human health, safety or social equality. Further, it must take into consideration technical innovation, quality standards, habits, standards of living and ideological visions.

Although it is possible to reduce the adverse effects of a policy intervention by adopting integrated policy combinations or 'packages' (see Deliverable 1, Oxford *et al*, 2010), and through appropriate methodologies, tools and models (see Deliverable 2, DLR and KIT, 2010), it is not possible to fully avoid unintended effects, foreseen or unforeseen. 'Real world' decision-making is always performed under uncertainty. These risks and uncertainties are due to the complexity of the transport system along with compounding risks and uncertainties concerning technology, markets, political context, socio-demographics and changes in values and preferences. Risks and uncertainties are particularly pertinent to the context of policy making at an EU level.

While the focus of Deliverable 1 and Deliverable 2 concerns reducing the incidence of unintended effects, this Deliverable focuses on the mitigation of unintended effects *ex-ante* and *ex-post*. *Ex-ante* mitigation of unintended effects favours reversible and flexible options acknowledging that decisions made under risk and uncertainty might lead to unintended effects. Thus the rationale echoes the need to keep the cost of reversing decisions as low as possible by incorporating risk management into the planning process. With availability of information gained from monitoring, it is possible to reduce risk and uncertainty, and necessary adjustments in policy design can be made *ex-post*. The availability of information can also help in early detection of unintended effects, known or unknown, and *ex-post* intervention to mitigate the unintended effects. Hence collection of necessary data (spatial, temporal, sectoral, etc) is an important and necessary part of addressing possible unintended adverse effects after the implementation of a policy measure or a policy package.

1.2 Purpose and overview

The main roles for this deliverable are:

- to extend analyses of risk/uncertainty beyond the complexities of the transport system to address the policy making process itself;
- to focus on "irreversibility" and causes of unintended effects with emphasis on path dependency and key lock-in effects that are pertinent to the transport system,
- to provide an overview of tools and models for integrating risk and uncertainty in the planning process, *ex-ante*;
- to review systematic approaches for collecting necessary information in order to reduce risk and uncertainties and for early detection of potential unintended effects,
- to develop a meta-framework for *ex-post*, remedial action which can facilitate the mitigation of adverse unintended effects and enhance desired impacts; and
- to emphasise the importance of flexibility in policy processes.

As shown in Figure 1.1, this deliverable draws on the contributions from WP2 (Deliverable 1; *Inventory of measures, typology of non-intentional effects and a framework for policy packaging*) and (Deliverable 2: *Inventory of tools and methods for early detection of adverse effects*). The contributions made in this deliverable will directly support tasks under Work Package 4 (*Best practice in package design*) by input from the procedural framework— for *ex-ante* and *ex-post* policy interventions. Also, results from this deliverable will feed into Work Package 5 (*Barriers for and good practises of implementation)* which will look in more detail into implementation issues, including the analysis of selected case studies.

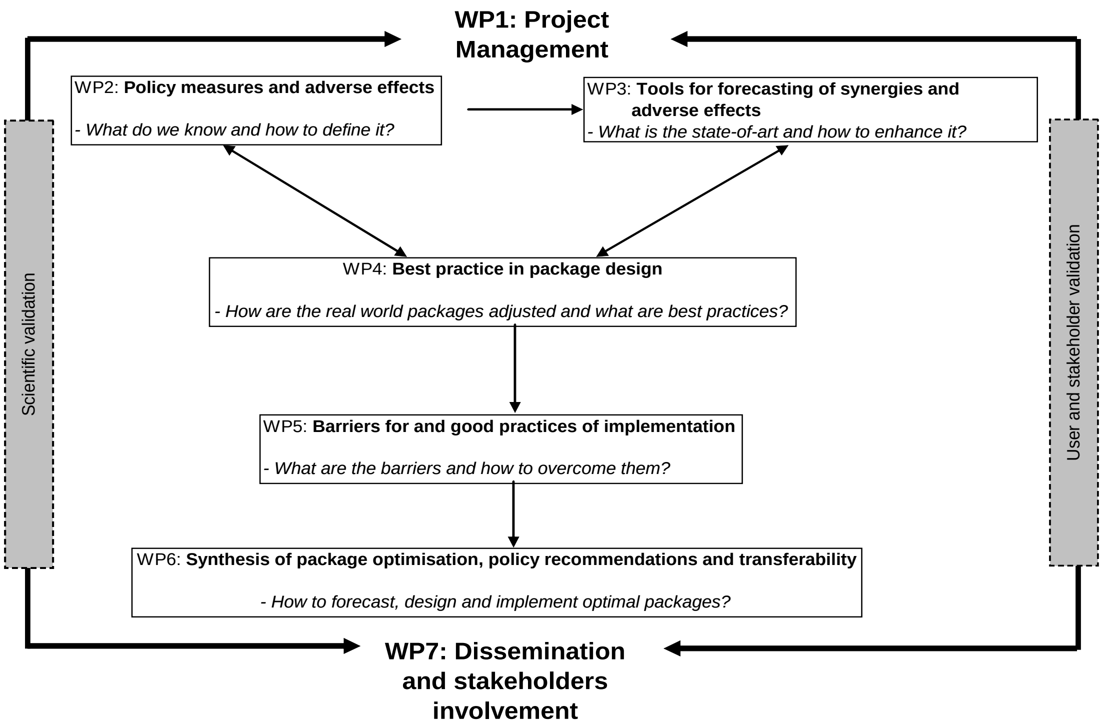


Figure 1.1 The structure of the OPTIC project.

1.3 Deliverable structure

Chapter 2 briefly presents different conceptualisations of risks and uncertainties and recommends—in response to the objectives and approaches of the OPTIC project—to address risks and uncertainties along the categories of 'knowns', 'known unknowns', and 'unknown unknowns'. A rather pragmatic distinction between 'removable' and 'non-removable' sources of risks and uncertainty associated with unintended effects is suggested and removable causes are briefly discussed. Chapter 2 also re-examines unintended effects, as described in Deliverable 1, and emphasises the importance of actors' situational knowledge. Coping with complexities plays a crucial role in the planning processes in this context. The more complex a system is the higher its uncertainty and thus the greater need for flexibility to be embedded in the design of policy measures. The traditional interpretation of robustness in planning should hence be extended to encompass this demand for flexibility. Flexibility is particularly important in the context of irreversibility; associated with the policy interventions (e.g., investment in infrastructure) or irreversibility with regard to the problem that the policy package aims to mitigate (e.g., environmental problems such as climate effect). This chapter emphasises that *ex-ante* and *ex-post* policy intervention for mitigation of potential unintended effects should be integrated in the planning process; a flexible decision making process that is open to remedial action based on *ex-post* analysis and evaluation.

Chapter 3 focuses on the notion of irreversibility, the interactions of irreversibility and uncertainty. The closely related subjects of path dependency and lock-in are also addressed in this chapter. An important cause for path-dependency in the economic domain is increasing returns. Some important sources of increasing returns in transport are presented in this chapter. The development of the car system is examined in the context of its increasing returns; network externalities encompassing several interrelated networks, supply externalities, learning-by-doing, economies of scale, increasing returns to information, and technological linkages, each with its own dynamics and critical mass, resulting in a path-dependent system. The chapter points to the inadequacy of the traditional models for policy design in the presence of risk, uncertainty and irreversibility, and for the prediction of outcomes under conditions of increasing returns.

Policy adoption is not always a now or never proposition. In most cases it is feasible to delay action and wait for new information.[1] With uncertainties and irreversibility, there is often leeway about the intensity and the timing of policy adoption, with significant potential implications for the optimal policy adoption path. Chapter 4 addresses the importance of irreversibility and their implications for policy design and describes methodologies available for the integration of risk and uncertainty in the policy design *ex-ante*. Three important policy areas in the transport domain at the EU as well as national levels where uncertainties and irreversibility are potentially great, are briefly addressed; alternative fuels and vehicles, infrastructure investments and environmental problems.

Chapter 5 examines how one might address policy limitations through *ex-post* monitoring and remedial action. In terms of monitoring, several main approaches and tools are distinguished. In terms of *ex-post* remedial actions, it is important to recognise that this deliverable makes no attempt to offer categorical solutions to situation-specific 'epistemic' or 'communicative' limitations. Rather as 'meta guidance', its purpose is to offer an overarching framework which can inform analysts who, upon the realisation that a policy intervention is unsatisfactory, are tasked with ensuring that it *becomes* satisfactory. This will be highly dependent on the problem context. Nevertheless, we have here outlined what ostensibly represents an extension of the *ex-ante* guidance detailed in Deliverable 1, set in the context of the analysis undertaken in Deliverable 2.

With acknowledgement of inherent risk and uncertainty, irreversibility and potential unintended effects in the policy arena, robustness as a decision criterion implies a demand for rethinking traditional approaches to decision making that assume a deterministic model of the world in which the future is predictable. Chapter 6 focuses on the challenges of flexibility in planning and the institutional challenges that this poses.

Concluding remarks are offered in Chapter 7.

[1] An example of a case where postponing action is not feasible is related to the urgency of the challenges posed by anthropogenic climate change with potential catastrophic consequences

2 Risk, uncertainty and unintended effects

This chapter focuses on characterisations of unintended effects in relation to risk and uncertainty. A huge body of literature on risks and uncertainties has emerged in recent decades (see for example Jaeger, *et al*, 2001; Renn 2008; Stern & Fineberg 1996). We briefly elucidate on selected aspects in this broad field and suggest a more pragmatic approach for policy making. This approach is presented in Section 2.2.1.

The subject of unintended effects is revisited in this chapter. The purpose is to first address the unintended effects that are related to policy interventions in the transport area and tools and methods for *ex-ante* analysis and mitigation of unintended effects. The second purpose is to illuminate the challenges of designing a policy process that is able to take into account all the necessary requirements for 'adaptive' policy packaging.

2.1 On sources of risks and uncertainties

Many authors state that in planning processes in general, and in transport planning in particular, risks and uncertainties are not adequately considered (see Gifford 1994, Grunwald 2007). Makridakis & Taleb (2009) argue that still a large number of decision makers and individuals believe that accurate forecasting is possible and that uncertainties can be assessed correctly and controlled effectively. On the other hand, it seems as if in the meantime the planning euphoria of the 1960s and 1970s is overcome and it is widely acknowledged that risks and uncertainty can never be fully avoided. Still, political rhetoric sometimes feed the impression that full control over the consequences of decision making is possible.

Risks and uncertainties are framed in different ways. We will rely here on a widely acknowledged definition introduced by Knight. In popular perception, 'risk' involves effects for which knowledge and parameters are available to assess the likelihood of an outcome; 'uncertainty' refers to a more genuine lack of systematic understanding of causal relations (Knight 1921, see also Runde, 1998 in OPTIC Deliverable 1). For example, noise effects on human productivity may partially be predicted and a risk assessment made; while noise effects on human creativity may be impossible to parameterise or even conceive.

Risk concepts are used in rather different meanings, and users emphasise different aspects of risks. The distinction and interrelationship between objective and subjective risks affects the integrated treatment of risks in a policy context (see Assmuth & Hildén 2008). Further, there are many economists that do not follow the Knightian categories and effectively deny the existence of uncertainty (see for example Friedman 1976). However, it is not the main task of this Deliverable to deepen the discussion about different conceptualisations of risks and uncertainties. For our purposes, we consider the Knightian categories to be adequate. The focus should rather be on the criteria that can be used for the identification of different types of risk and uncertainties. There are several approaches for a classification of risk and uncertainties; these could be related to their consequences or to their sources. For example, Renn & Klinke (2002) proposed the following criteria for evaluating the consequences: risks and management strategies: extent of damage; probability of occurrence; incertitude; ubiquity; persistency; reversibility; delayed effects; violation of equity; potential of mobilisation. These criteria demand the integration of very different types of information (see Assmuth & Hildén 2008).

A simple categorisation of the sources of risk and uncertainty can be derived from the Knightian definition of these two terms. This definition is related to the kind of knowledge that is available in relation to a process or a phenomenon. Going back to the notion of Knight in general, risk is considered as something that has known probability distributions with observable outcomes. However, the process or phenomena cannot be fully controlled. It could be too complex and/or partly not well enough understood. 'Inside' the transport system, data might not be available and/or resources to collect data are not available. 'Outside' the transport system, external factors that are known but cannot be influenced by transport policymakers might develop in a disadvantageous way. Examples for such external factors are the development in oil prices, demography, climate change, a stock market crash, globalisation or geopolitical conflicts. If there is less knowledge in relation to internal or external factors, or on the causal relations between factors, there is uncertainty.

Kleindorfer (2008, p. 7) refers to two basic types of risks associated with the availability or absence of knowledge. Epistemic risks arise from a lack of knowledge about the appropriate model or theory that might be relevant for a particular phenomenon. Furthermore there are "aleatory" risks that arise from randomness inherent in the phenomena (though this randomness itself can be defined or qualified by the underlying epistemic assumptions). Kleindorfer further points out that "while there is a grey area between what is epistemic and aleatory risk, the key difference is that epistemic risk can be reduced through exploration and knowledge acquisition, whereas aleatory risk cannot be reduced by such informational activities" (*ibid.*). These differences are relevant for the treatment of corresponding risks and have to be taken into account for the *ex-post* analyses of unintended effects and corresponding remedial actions. They further illustrate that there are two types of risk: those that can be managed in policymaking and those that cannot be tackled adequately. The latter have to be taken as given. The fact that such a category of aleatory risks exists underpins the need for *ex-post* assessment and evaluation of policy interventions, for remedial action plans and for a certain degree of flexibility in policy processes.

Deliverable 1 of the OPTIC project draws on the work of the sociologist Merton (1936) for the analyses of unintended effects. Merton emphasises the importance of knowledge gaps for the occurrence of policy failures. As potential reasons for such policy failures he identifies: ignorance, error, bias and feedback effects. So, this is rather related to 'epistemic risks' in the terminology used by Kleindorfer.

Van Asselt & Rotmans (2002) analysed published knowledge on uncertainties and concluded that two broad categories of uncertainties can be distinguished which are quite similar to the aleatory and epistemic categories introduced by Kleindorfer (2008), respectively:

- Uncertainties due to variability. Sources of such variability could be: Inherent randomness of nature, value diversity, human behaviour, socio-economic and cultural dynamics (societal randomness), socio-technical surprises.
- Uncertainty due to our limited knowledge of the system: inexactness, lack of observations/measurements, practically immeasurability, conflicting evidence, reducible ignorance, indeterminacy, irreducible ignorance

So, it was illustrated in this subchapter that rather different interpretations and conceptualisations of risks and uncertainties exist. We rely here on the Knightian argumentation. Regarding the sources of risks and uncertainties, various, often overlapping, categorisations can be found in literature. Taking into account the objectives and approach of the OPTIC project, in the following chapter we suggest a pragmatic approach to overcome this variety in definitions and conceptualisations.

2.1.1 A pragmatic approach to sources of risks and uncertainties

The transport system is embedded in broader social, economic and environmental systems. From a policy analysis perspective, the transport system with its components and their interrelations could be understood as an abstract conceptual model and as a web of nodes that are interlinked with each other. As a good approximation, one might think of climbing nets that can be found on children's playgrounds, see Figure 2.1. In OPTIC Deliverable 2 (DLR and KIT, 2010) this example was used to exemplify the issue that quantitative models are able to reproduce only a cut-out of this web. Certain nodes and links are out of the scope of quantitative models and most likely need to be analysed either by an enhanced model or other types of assessment approaches.

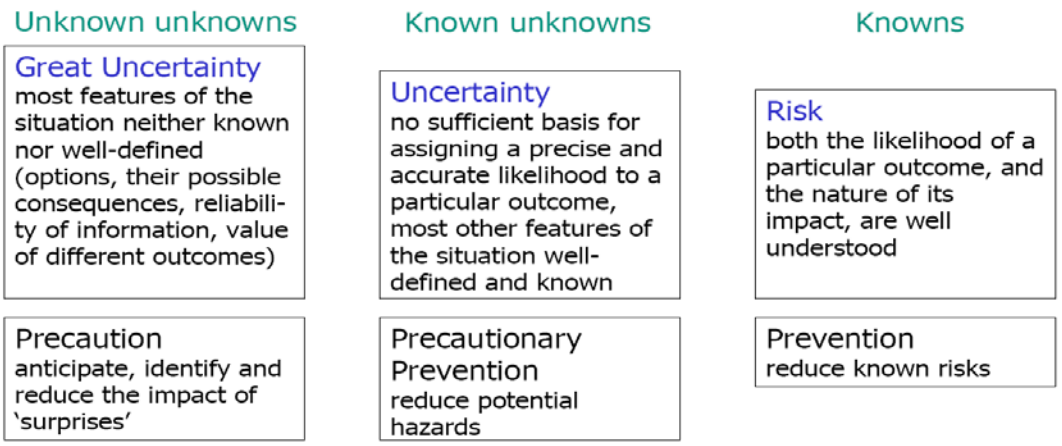
Figure 2.1 Children's climbing net as an approximation to the web of nodes

Many of these nodes and links are known and well-described, some nodes and links are known to be existing but not sufficiently conceptualised, and a third group of links and nodes are completely unknown. This widely corresponds with the categories, 'unknown unknowns', 'known unknowns' and 'knowns' illustrated in Table 2.1 below. Obviously, timing is quite important for this categorisation. For the category of unknown unknowns only *ex-post* examples are possible, because as soon as an item is selected as an example, it cannot be completely unknown anymore. The examples further indicate that with increasing knowledge, an issue is shifted from 'unknown unknowns' to 'known unknowns' and from 'known unknowns' to the 'risk' category. For example the effects of motorisation on urban sprawl are well known today but have been unknown some decades before. Therefore, it is not always an easy task to allocate the examples to exactly one of the three categories; other interpretations of the situation are possible.

Remaining with the 'web of nodes', a policy intervention in the transport sector directly affects at least one, maybe several of these nodes. At the same time, a number of other nodes can be affected indirectly, via the links. The directly and the indirectly affected ones start swinging and influencing each other, they can produce rebound effects. The model illustrates that a policy intervention can lead to wide ranging effects, and some of them only become visible after the measure has been implemented.

Again, as was discussed above, quantitative models such as TRANSTOOLS or TREMOVE work only with a cut-out of the web and enable the study of a certain area of the web. It is not possible to detect any effects in excluded areas by applying these models. So, if we are not able to reproduce the whole web since there are too many relationships also to areas beyond the transport system (e.g. energy, land-use, and economy), uncertainties and risks cannot be excluded.[2] This illustrates the relevance of explorative scenarios and the integration of qualitative assessment approaches to get a better understanding of the relevance of external factors. Such scenarios allow for playing through different situations, for example an extremely high oil price or an accelerated climate change; they enable an assessment of how the web of nodes reacts on such external triggers.

[2] Picht argues in 1967 that modern science is based on the isolation of causalities and effects; this implies a methodological blindness against secondary effects; causalities leading to these effects have been excluded on purpose.



Examples for Unknown unknowns	**Examples for Known unknowns**	**Examples for Knowns**
Car friendly urban policy in the 1960's leading to congestions several years later Car friendly urban policy in the 1960's leading to urban sprawl From an 1970's perspective: heavy growth rates in freight transport in the EU on roads from and to Eastern European countries	Effect of a bypass road on kilometres driven in an area (additional traffic might be attracted) Barrier effect (new road) on biodiversity Effects of market penetration of electric vehicles on travel patterns (e.g. on modal split) Consequences of global warming on economic growth	Effects of speed limits on emissions and number of accidents Health problems caused by noise or pollutants Effects of fuel prices on person kilometres driven in a region Correlation between the development of GDP and growth rates in freight transport
Note: the allocation to categories is done here for illustrate purpose and might differ according to actor perspectives		

Table 2.1 Risk and uncertainty in decision making with examples from transport **(**Source: Fleischer, 2008)

It is argued that we rather should focus on the reasons for risks and uncertainties than on their different conceptualisations. It is rather important to get a clearer picture of the limitations concerning epistemological access to the web described above. Why do we have incomplete knowledge and what can be done to improve the situation? The primary key-question is if the limitations in knowledge are removable or not. Therefore, it seems to be important to differentiate between:

1a) Easily removable limitations and bottlenecks

1b) Limitations which are difficult to remove

2) Non-removable bottlenecks and limitations

This is related to the classification introduced by Kleindorfer and described in Section 2.1 because 1a and 1b are falling in the category 'epistemic risks', whereas Reason 2 is similar to 'aleatory risks' according to Kleindorfer's terminology.

2.1.2 Removable sources of risk and uncertainty about unintended effects

Inside the category of 1a and 1b, which are related to removable risks (or epistemic risks) it is possible to identify different causes of unintended effects. For example according to Merton's (1936) *The Unanticipated Consequences of Purposive Action* (cf. Deliverable 1), unanticipated effects are caused or have to do with a) information availability, b) the (planning) procedure of decision-making, c) effects of different weighting of consequences or d) the policy-making process itself that can have an effect on (public) opinions and thus, alter the expected (unintended) effects. In sum, these categories refer to the procedural aspect (planning), the data and informational aspects and the effect that human behaviour has when it comes to unintended effects. Respectively, in Deliverable 1 some of the main causes for such effects were already identified. Note that we assign the categories of the core typology of effects and situations (Oxford *et al*., 2010, p. 44) to the categories of removable effects:

- Basically removable: policymakers[3] *weight* in a partially or complete inaccurate way the elements of causal relations which can lead to 'surprising' results (positively, negatively) although the underlying model captured adequately the causal relationships ('Overdone'; 'Off the Mark') // assuming a correct causal model; not intentionally
- Basically removable: policymakers *omit* part of the causal assumptions ('Spill Over'; 'Not-In-My-System') // assuming a correct causal model; not intentionally
- Basically removable: policymakers *omit (ignore)* part of the causal assumptions ('Blind Spot'; 'Blind Spot with a vengeance'; 'Secondary Blind Spots') // assuming an inaccurate causal model; possibly intentional due to ignorance, optimism bias, time pressure, hubris or pursue of own interests
- (Not removable: system related and long-term ('Holy Smoke') // assuming a correct or inaccurate causal model; intentional or non-intentional; absolutely not foreseeable);

Further causes of unintended effects are e.g. lock-in effects and the related issue of irreversibility (see Chapter 3). It can be contested whether lock-ins and irreversibility are always removable. But it is argued that potential consequences of irreversibility and lock-in are in many cases not taken into account adequately. So, there is some scope to remove causes of unintended effects. For current models it is very difficult or even impossible to

[3] We assume here the policymaker to determine the setting of the analysis. This means, he/she decides which method/model to use and the variables to consider in the analysis. In many cases, this would be a process where the policymaker requires consultation by experts. But, the final decision about weighting of variables and interpretation of results remain with the policymaker.

estimate the impact of these types of effects. A transport network model will predict correctly the effect of a new highway in the short-term (reduced travel time, improved accessibility), but it will hardly be able to estimate secondary effects in the long-term, e.g. on land prices or the socio economic composition of neighbourhoods. If such an unintended effect and its potential cost for the public are not taken into account during the evaluation of the measure, the result will most probably be biased assessment of results and suboptimal decision-making.

Given the limited scope of models, we may assume that decision-making is expected to be done against the objective of achieving a social optimum taking into account the 'best' information available. But, this 'best' decision, based on the information available still implies assumptions—for example, that the methods and models used for the evaluation of alternatives work correctly and that decision-makers consider all the relevant information. The latter point opens up the floor for an additional cause of unintended effects. The individual—here the decision-maker—is limited in processing and evaluating information of all decision alternatives. Kahneman and Tversky (1979) summarise this by saying that people are limited in their ability to comprehend and evaluate probabilities of extreme outcomes and that highly unlikely events may be ignored or else overestimated. As a result situations appear where the policymaker due to the limitation in processing and evaluating all options omits and/or ignores relevant aspects of the causal assumptions. This probably leads to a selection of partially biased decisions that do not reflect the 'best' option according to the objective of achieving a social optimum. As mentioned above, this could be done on purpose or non-intentionally.

Another underlying cause for unintended effects can be rent-seeking. Rent-seeking related to policymaking can appear from both sides, either from the politician or from the bureaucrat, whereas both seek to extract an additional rent by following non-altruistic behaviour. This rent may come from campaign funding, gifts, future career opportunities or bribes, in other words rent creation (typically in the form of laws or regulations written in order to target a specific interest group; duly or unduly).

Based on this reflection the following major areas for prevailing removable causes of unintended effects are suggested:

C1. Economy: economic development and underlying market mechanisms are crucial impact factors when it comes to unintended effects. 'Lock-ins' have to be considered where the reversibility of policies becomes difficult; thus, remedial action for the mitigation of unintended effects is related to high costs or requires long durations due to the consistency of the policies implemented in the first place. Regarding individuals, rent-seeking and the search for personal, economic benefit can cause intentionally wrong or biased assumptions when it comes to the assessment of policies.

C2. Institutions: institutions and their beliefs/interests influence the behaviour of policy-makers. They may produce 'pressure' to move decisions (policy definitions) towards a convenient expected outcome and, as a result, decision-makers may weight incorrectly and/or omit (ignore) causal assumptions. Also, due to uncoordinated intra- or inter-organisational behaviour, relevant effects (intended, unintended) might be overlooked.

C3. Individuals: the causes for unintended effects are similar to those produced by the institutional category but remain individual and intentional or non-intentional (incorrect weighting, omission (ignorance) of causal assumptions); the processing of available information by the individual is limited and by nature decisions may not be based on the total information available. Personal beliefs or interests used to achieve individual benefits are most likely a frequent cause for the appearance of unintended effects (overlap with C1 'Economy': tendencies of rent-seeking behaviour). Time-preferences also play a role as they may change long-term objectives for the sake of short-term results with reduced effectiveness in the long run.

C4. Complexity: the issue of complexity is related to a) analytical models and b) organisation and actor involvement. If the models are analytically too simple, relevant aspects of human behaviour are left out and the results do not encompass all important aspects. If, on the other hand, they are too complex, results are difficult to understand and most probably not taken into account. The risk of unintended effects here is a 'bad' interpretation (or even no interpretation at all) of modelling results (wrong weighting, omitting or ignoring results).

Actor involvement becomes complex, especially when different institutions are involved in the policymaking process (horizontal integration) and responsibilities not clearly defined (this issue is also related to institutional structure and thus an overlap to category C2 'Institutions').

C5. Planning: unintended effects can also be caused by the course of the policymaking process itself. Discussions about policies and their impacts before implementation most probably influence the design of the policies and thus can create 'biased', suboptimal outcomes. Planning regulations/laws and their 'translation' into action can cause unintended up to counter-intentional effects. Consider the example in OPTIC Deliverable 1 about tendering conditions and their responsibility for bias in estimates of benefits, costs and risks: 'underestimating costs and overestimating benefits is, of course, a rational approach to securing funding in a competitive market' but with the counter-intentional effect of winning those tenders with 'greatest cost overruns and benefit shortfalls in practice' (Oxford *et al*., 2010, p. 88).

2.2 Revisiting unintended effects

In this section we briefly present reflections on different kinds of unintended effects, on methods for the identification of unintended effects and on the related design of policy intervention. This review is based on previous work done in this project, so its purpose also is to briefly reiterate key-findings of Deliverables 1 and 2. Understanding the transport system as a complex system with a large amount of interdependencies we will distinguish between first order and second order complexity. The idea is that first order complexity is related to the socio-technical system as a whole that has to be governed. The second order complexity is related to the challenge of designing a policy process that is able to take into account all the necessary requirements for ‘adaptive’ policy packaging.

2.2.1 Unintended effects; avoidable and unavoidable (first order complexity)

The first order of complexity is related to policy interventions. Very different unintended effects can result from policy interventions. For example, the introduction of a road charge for highways leading to underestimated problems on ancillary roads, the construction of a bypass that is leading to a modal shift from rail to motorised individual transport and potentially to a decrease in biodiversity because of segregation effects. Park and ride facilities aiming at increasing shares of public transport might lead to urban sprawl and increased car travel in the long run. A CO_2 differentiation in motor vehicle taxation can induce a shift from gasoline to diesel cars resulting in increased local emissions (NOX and PM_{10}-$PM_{2.5}$). Further examples of unintended effects are given in OPTIC Deliverable 1 (Oxford *et al*., 2010).

As discussed in Section 2.1.3, at least two groups of unintended effects can be distinguished: those that can be avoided and those that cannot be avoided. This differentiation indicates that a typology of unintended effects is helpful and needed to provide a basis for designing policy strategies to cope with unintended effects. Therefore, in Deliverable 1, a typology of unintended effects—here represented as Table 2.2—was introduced. Effects that are known or at least anticipated are distinguished from effects that have not been known in advance. Of course, the actor perspective is important in this context. For simplification we focus here on the perspective of decision-makers that are responsible for a policy intervention or a programme (even though this is clearly not a homogenous class of actor). In addition, it should be emphasised that the categories in Table 2.2 are of analytical character. They help to identify adequate methods for an *ex-ante* or an *ex-post* assessment of unintended effects and support the development of a systematic approach for policy packaging. The effects listed in the W (known) categories can be understood as risks, whereas those listed in the X (unknown) categories are uncertainties.

The typology illustrates that unintended effects are not necessarily negative or adverse; they might well be advantageous. There is not always a link between intention and knowledge. However, at least in the light of a technocratic planning paradigm, unknown effects seem to have a negative connotation since in any case (positive or negative) they have not been anticipated by the planners or promoters of the intervention (see Gloede 2007).

It should be noted that Deliverable 1 provides also a much more detailed typology of unintended effects. To maintain continuity in the following chapters, we refer to the more aggregated typology presented in Table 2.2 as this is perceived as a sufficient distinction between unintended effects for the objectives aimed at in this Deliverable.

		Consequence dimension		
		A. Intentional	B. Non intentional	
			B1 Counter intentional	B2 Secondary
Knowledge dimension	W. ‘Known’	The consequences that decision makers intended with the intervention ------- *Average fuel consumption of new vehicles is reduced; less fuel is consumed*	Counter-intentional effects that were anticipated at the time of decision ------- *Cars are driven longer and consume more fuel due to lower fuel cost/km (rebound effect); models may predict the effect*	Secondary effects that were anticipated at the time of the decision ------- *Longer distances driven lead to increase in congestion; models may predict the effect*
	X. ‘Unknown’	Advantageous effects that are not known; serendipitous ------- *New cars inspire some people to ‘green driving’ lifestyles, saving additional energy*	Counter-intentional effects not known at the time of decision ------- *Car manufacturers economically challenged by the standard abandon plans to develop ultra light cars*	Secondary effects not known at the time of the decision ------- *Less public propensity to use alternative travel modes due to cheaper car travel, leading to line closures*

Table 2.2 Consequences versus Knowledge, with a speculative example of a fuel efficiency standard (Source: *OPTIC,* Deliverable 1)

2.2.1.1 Tools and methods for *ex-ante* analysis of unintended effects

Even if unintended effects cannot be fully avoided, there is scope for reducing their likelihood. It is discussed in OPTIC Deliverable 2 (DLR and KIT, 2010) that the unintended effects can be reduced by using tools and methods for anticipation and assessment of such effects. Many of the methods usable for *ex-ante* analyses can also be used for an *ex-post* analysis. In addition, the *ex-post* situation offers other possibilities for the application of methods than the *ex-ante* situation. For example, an evaluation using empirical data (costs and revenues, transport volumes, number of trips, modal split) is only possible following measure implementation.

These tools and methods can either be rather explorative in character, very open in terms of scope and variables included, or they can be structurally closed, with an analytical rather than an explorative focus. For these structurally closed methods, a more or less concrete understanding of relevant parameters and their interrelations does already exist and the focus is on getting a better understanding on what happens if these variables or the relationships between them are changed (see Table 2.2). A typical example for a structurally open and explorative approach is ‘brainstorming’, where ideas are simply collected and—at least in the first instance—neither overly criticised nor rejected outright. Classical examples for a strongly analytical tool are models, such as TRANSTOOLS or TREMOVE.

Structurally open methods	**Structurally closed (pre-defined) methods**
• no fixed setting • mainly explorative • never purely quantitative, strongly shaped by qualitative elements • in principle open to detect effects beyond the system boundaries	• pre-defined setting • mainly for analyses of specific situation • more of less clear understanding of the relevant parameters, the linkages between these parameters and the way the parameters affect each other • mainly quantitative data used • focus on effects inside the predefined system • effects outside the system cannot be detected
Examples: brainstorming, open space, expert workshops, explorative scenarios	Examples: Models such as TRANSTOOLS and TREMOVE

Table 2.2: Categorisation of tools and methods for the early detection of unintended effects (Source: OPTIC, Deliverable 2)

In essence, the structurally open methods are more shaped by qualitative information whereas the structurally closed methods are base on quantitative elements. However, many tools are in between structurally open and structurally closed, thus, there is a continuum between these two poles. This categorisation is even more blurred by the fact that many methods are actually a combination of different individual tools. For example, scenarios are applied using an open structured, explorative workshop at the beginning to pre-define the settings that are used for a quantitative model-based analysis. Finally, the results can be discussed with stakeholders in a workshop with a rather open format again. As it was illustrated in Deliverable 2, it is the adequate application of structurally open and structurally closed methods during the policy packaging process that allows for the detection and the assessment of unintended effects.

As a result of Deliverable 2, the recommendation was given to use structurally open methods in an explorative phase at the beginning of the policy-making process. Qualitative deliberation is important, for example, to exclude obviously unrealistic policy options at an early stage. Additionally, the structurally open methods, applied consequently, allow for the identification of the principal unintended effects. Structurally closed methods, such as models TRANSTOOLS and TREMOVE are applied in the middle of the planning process in an analytical phase where quantification is the main objective. In this phase, work is dominated by experts. Finally, structurally open methods are again recommended for the interpretation of results, probably including once again the affected public and/or involved stakeholders. We suggest that the higher the number and type of policies combined in a package, the less purely quantitative methods are usable and thus, methods of a structurally open character are recommended.

2.2.2 Policy packaging and the policy process (second order complexity)

It is clear that tools and methods have to be integrated in and adopted to the practice of policymaking. It was illustrated in Deliverable 2 that ‘timing’ is highly important for making efficient use of tools and their combination. This means that some tools perform best in certain phases of the process of policymaking. However, the policy process itself might be of iterative character, since after implementation and evaluation *ex-post* a new, secondary planning process starts in response to the effects induced by the primary planning.

The paragraphs above already indicate the enormous challenge that imply a combined *ex-ante* and *ex-post* assessment of the policy package and the threat that assessment requirements gets too demanding to be connected to the daily practice of policy making. We are facing here what can be called ‘second order complexity’. First order complexity was related to the transport system as a whole and its components, second order complexity is related to the specific policy process that has to be designed carefully to be able to take into account all the necessary requirements for an “adaptive” policy packaging (see Figure 2.2).

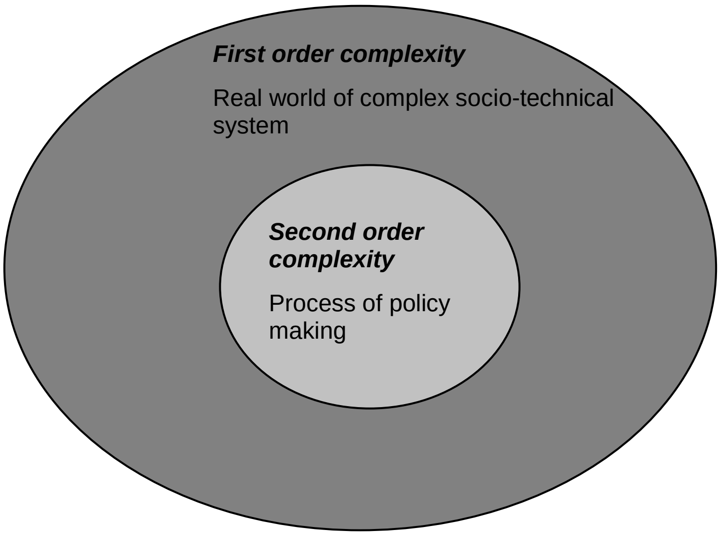


Figure 2.2 First and second order complexity of governing socio-technical systems.

In Deliverable 1, sequences of an iterative policymaking and packaging process were proposed and are briefly resumed in this chapter (see Figure 2.3). Illustrations of more detailed approaches can be found, for example, in Walker *et al*. (2001) or in Marchau *et al*. (2008). Understanding policymaking as an iterative process is important precisely because of the issues of flexibility and reversibility. Expecting unintended effects *ex-ante* or detecting unintended effects *ex-post* only leads to improvements if there is room for changing or supplementing the primary planning process, in other words: if there is room for remedial actions.

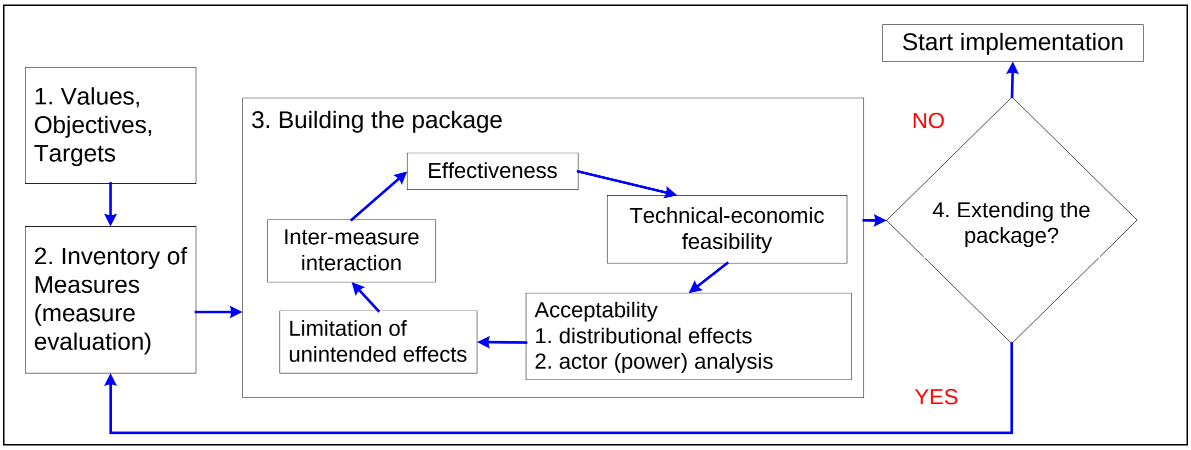


Figure 2.3 Sequences of an iterative policymaking and packaging process (modified on basis of OPTIC Deliverable 1)

2.3 Summary and Conclusions

A wide range of different conceptualisations of risks and uncertainties exist. For the purpose of the OPTIC project, a pragmatic approach to risks and uncertainties and the underlying reasons is required. Such an approach is introduced for the classification of risks and uncertainties and for potential reasons of risks and uncertainties. It is suggested to categorise risks and uncertainties along the categories: ‘unknown unknowns’, ‘known unknowns’ and ‘knowns’:

- For the category of ‘knowns’ or risks we know that there could be an adverse effect. However, due to the complexities of decision making (disagreement about goals and means how to achieve these goals), and misperceptions about the importance of the adverse effect, the adverse effect has not been addressed adequately and becomes visible as an unintended effect after implementation. There is also the possibility to ignore an adverse effect that is actually known, when the adverse effect is outside the system that the policymakers have jurisdiction over.

- Known unknowns: There is an understanding of the adverse effects; however, there is no possibility to reliably assess the probability of their occurrence or the extent of their impacts. It can be important to address these effects (e.g. consequences of global warming), but as more information becomes available, policies and plans need to be adjusted and hence there is a need for flexibility and adaptability in planning.

- Unknown unknowns: Given the complexities of the transport system and its links with related policy domains, we should expect completely unforeseen unintended effects. Hence, it is important to built in sensitive monitoring and evaluation methods and ensure adaptability and flexibility in the planning and implementation processes. In doing so, it should be considered that these ‘unknown unknowns’ are often associated with longer time horizons.

It is emphasised that removable reasons for risk and uncertainty associated with unintended effects exist in addition to non-removable reasons. As a result, unintended effects can never be fully excluded from the planning process. On the other hand, a broad range of causes of unintended effects exist which are removable in principle. Managing complexity is of crucial importance in this context. The more complex a system is, the higher its uncertainty and thus the greater need for flexibility to be embedded in the design of policy measures.

In the context of such reflections, the relevance of the time horizon is also significant. In general, risk and uncertainties increase with an extended time horizon as important factors change over time such as technological developments, user perceptions, socio-demographic factors, availability of resources, economic conditions and socio-political, institutional contexts.

Once an *ex-post* assessment has revealed the presence of unintended effects, remedial action may be needed. Policy options for remedial action can result in the requirement of integrating additional measures in the initially defined policy package, or possibly the removal of an existing measure. In particular, for the latter option, reversibility or irreversibility of policy interventions and the closely related subject of path dependency and lock-in effects are important issues that will be dealt with in Chapter 3.

For the design and evaluation of policy packages it is important to be aware of the fact that unintended effects of policy intervention can be reduced but cannot be fully excluded. The typology of unintended effects developed in Deliverable 1 acknowledges the existence of such effects and describes some of their characteristics. It further demonstrates the importance of actors’ situational knowledge. The question to what extent unintended effects are avoidable is relevant for the discussion of remedial action and *ex-post* analyses. In situations where there is risk and uncertainty in relation to crucial parameters, it is necessary to carefully use tools and methods for integrating risk and uncertainty in the policy design, and it is important to design flexible and adaptive policies that can be adjusted when availability of information resolves risk and uncertainty (see Chapter 4). At the same time it is important to apply monitoring and evaluation tools, in order to ensure early *ex-post* identification of unintended effects once a policy intervention has taken place (see Chapter 5).

A wide range of different tools and methods are used in policy assessment and evaluation. It is not always an easy task to find or design the best methodological approach to support a planning process. The inventory of tools and methods, as it was provided in Deliverable 2, supports the policy process in terms of goal achievement, since it addresses possibilities and limitations of the different approaches.

One of the key questions of this Deliverable is whether, in spite of the huge variety of effects, guiding principles for *ex-post* corrective actions procedures can be formulated. Such guiding principles have to be discussed on the one hand in relation to the tools and methods needed, and, on the other hand, against the background of the requirements for flexibility and adaptability of the policymaking process and the actors and institutions involved (see Chapter 5 and 6).

3 Irreversibility, path dependency and lock-in effect

This chapter provides definitions of irreversibility, path dependency and lock-in effect. These phenomena are closely related. It further explores how costs and benefits associated with a policy are affected by risk and uncertainty and how risk and uncertainty affect discounting of the benefits and costs. These points suggest that the traditional methods of policy appraisal are limited in accuracy and result in the presence of bias in evaluation procedures. Chapter 4 briefly describes methods used for policy designs in these situations.

In economics, path dependency and 'lock in' effects are explained by increasing returns. We briefly describe the most relevant sources of increasing returns in the context of the transport domain. The core properties of increasing returns are non-predictability, potential inefficiency of outcomes, path dependency and lock-in. It is emphasised that traditional models in economics are not appropriate for the prediction of outcomes and it is not easy to escape from a lock-in situation using the *de facto* tax or subsidy policies prescribed by economists. Finally, path dependency in the transport system is described with the example of the development of the 'car system'.

3.1 Irreversibility

There is a large and mounting body of literature that explores the implications of irreversibility. The key questions concern the extent to which irreversibility matters *per se* and what implications irreversibility has for the design of policy interventions (Pindyck, 2007).

In the literature there are different interpretations of irreversibility. One interpretation is when return to the status quo is impossible or extremely difficult, at least on an appropriate timescale. An alternative interpretation sees irreversibility in terms of sunk cost, corresponding to the definition in economic literature on options (see Sunstein, 2008).

For environmentalists, irreversibility is associated with large-scale change in environmental conditions. The relevance of irreversibility here lies in its association with damage of extreme magnitude. In real options theory, however, irreversibility is defined in a technical manner. Irreversible investments are sunk costs, those costs that cannot be recovered totally. An example of an expenditure that can't be recovered is investments in transport infrastructure, which are usually assumed to represent sunk costs.[4] Even the purchase of a motor vehicle is only partially reversible since purchase cost substantially exceeds resale cost. Buyers in used car markets are often unable to fully evaluate the quality of cars in the market and tend to offer a price of an average car. Sellers that have an above average car are thus reluctant to sell at this price. This will lower the average quality and, in turn, market price (Pindyck, 2007). This so-called 'lemon problem' can be found in many similar

[4] Most often investment expenditures that are firm or industry specific are sunk costs. It is difficult to sell them in the market, especially if ex-post they turn out to be bad investment according to some welfare criteria.

markets (Arkelof, 1970). Irreversibility can also arise due to government regulation or institutional arrangements (Dixit and Pindyck, 1994).

There are usually important irreversibilities associated with environmental policy. These irreversibilities can arise not only with respect to environmental damage itself, but also with respect to the costs of adopting policies to reduce the damage. Regulation that reduces one environmental risk might well increase other environmental risks; efforts to reduce the CO2 emission associated with fossil fuels, may lead to increased dependence on other sources of energy that have associated economic and environmental costs. We are facing irreversibilities, not irreversibility. There is almost always uncertainty over the future costs and benefits of adopting a particular policy and these can often work in opposite directions (see Sunstein 2005 and Pindyck 2009).

Environmental policies impose sunk costs on society. Improvements in fuel efficiency require capital costs (and running costs[5]), and they cannot be recovered. In addition, political constraints may make an environmental policy itself difficult to reverse, so that these sunk costs are incurred over a long period of time, even if the original rationale for the policy disappears. If future costs and benefits of the policy are uncertain, these sunk costs create an opportunity cost of adopting the policy, rather than waiting for more information about environmental impacts and their economic consequences. This implies that traditional cost-benefit analysis will be biased toward policy adaption (Pindyck, 2009).

On the other hand, environmental damage can be partially or totally irreversible. For example, major greenhouse gases are well-mixed, and take many years to leave the atmosphere and with additional emissions of GHG, result in high concentrations that are long lasting. And the damage to ecosystems from higher global temperatures can be permanent. This means that adopting a policy now rather than waiting has a sunk benefit—that is, a negative opportunity cost.[6]

The problem with an irreversible investment is that new information might affect the desirability or timing of the expenditure, and a lost option value is an opportunity cost that must be included as part of the evaluation of the investment. In most cases it is feasible to delay action and wait for new information. With uncertainties and irreversibilities, there is almost always leeway about the intensity of the policy and the timing of policy adoption with significant effect on the optimal policy adoption path (see Dixit and Pindyck, 1994: Pindyck, 2009), although clearly there are certain problems—such as anthropogenic climate change—where such leeway is significantly restricted through urgency.

[5] Running costs refers to those related to different supporting industries rather than running cost of alternative fuel vehicles

[6] This point was made early in works by Arrow and Fisher (1974), Henry (1974), and Krutilla and Fisher (1975).

3.1.1 Irreversibility, risk and uncertainty

Environmental problems usually involve three compounding levels of uncertainty: uncertainty over the underlying physical or ecological processes; uncertainty over the economic (and social) impacts of environmental changes; and uncertainty over technological changes and behavioural changes that might restore those economic and social impacts and/or reduce the cost of limiting the environmental damage in the first place (Pindyck, 2007).

Irreversibility only matter if there is uncertainty. Pindyck provides the following example to illustrate the point. If today we knew precisely how society values a pristine wilderness area every year over the next two hundred years, and if we knew what would be the annual flow of profits, wages, and consumer surplus over that same period from the conversion of the wilderness into a commercial resort, and if we knew the correct discount rates that would apply over the same period, we could then calculate present values and do a simple cost-benefit comparison of the pristine wilderness and the commercial resort. If the comparison favoured the resort, we could allow commercial development, knowing that nothing would change in the future that would cause regret and lead to a desire to 'undo' the loss of the wilderness. Likewise, if the comparison favoured the wilderness, we could prevent commercial development, knowing that nothing would change that would cause regret over the loss of surplus from a resort. Irreversibility would be irrelevant. Uncertainty can affect policy even if there is no irreversibility, but in a more limited way than if irreversibility is present.

The uncertainties over costs, benefits, and discount rate have major consequences for the conventional models that assume stability of these parameters over time. The quantitative models that have been addressed in Deliverable 2 are all of this nature. In Chapter 4, models for integrating risk and uncertainty into policy design are discussed.

Uncertainties over benefits and costs are related to the parameter uncertainty (e.g., uncertainty over the elasticity of emissions with respect to a tax rate on emissions), but also to the form of uncertainty over the shapes of the (nonlinear) benefit and cost functions (e.g., uncertainty over how that elasticity falls as the tax rate is increased). These problem becomes especially severe when there are ''tipping points'' (i.e., when at some level of environmental damage the consequences become near-catastrophic), but we do not know what that point is. Discount rates are inherently uncertain, and a long time horizon makes this uncertainty especially important (*ibid*.).

Uncertainty over benefits

Dixit and Pindyck (1994) describe the standard approach to modelling investment under demand uncertainty when investment decisions are partially or totally irreversible. This generates real options on the investment decision and a separation of the thresholds for investment and disinvestment, with no investment undertaken in between these thresholds. Even low levels of uncertainty and irreversibility can lead these thresholds to be significantly spaced apart in relation to their positions under complete certainty and reversibility.

Pindyck (2009) focuses on the uncertainty over the benefits of an environmental policy. He points out that the aim of a policy in this context is to bring human use of environmental assets closer to socially optimal levels and hence to create social benefits. The aim of a carbon tax is to result in benefits (reduction in economic impacts of global warming) and that benefits should be larger than the costs of the policy. The timing (when to impose the policy) and the intensity (the extent) of the policy depend on the specific benefit functions; that is, on how the benefits from the tax vary with its size. And the answers also depend on the nature and extent of uncertainty over those benefits. Pindyck also points out the possibility of a tipping point in the benefit function, a point after which adaptation do not work, and there are uncertainties associated with the tipping point. He summarises that in the case of global warming, which has been studied quite extensively, we know very little. We know that there is a good deal of uncertainty, but we are hardly able to quantify it, especially when it comes to tipping points.

There are other policies, especially with impacts over long time horizons, with uncertainties over the benefit function (and the cost function) and hence the timing and the intensity of the policy should be treated in a similar manner to an environmental policy.

Uncertainty over costs

An investment problem faces two types of uncertainties over its cost. One is referred to as 'technical uncertainty' and it is connected to physical difficulty of finishing a project. Technical uncertainty can only be fully resolved by carrying out the project in order to get information about the uncertainties. The second type is referred to as input cost uncertainty and it relates to fluctuations in the price of labour and material and other inputs as well as regulatory regimes that are external to the project. Input cost uncertainty can be important for projects that take time to complete. Input cost uncertainty makes investment less attractive to be undertaken now (Dixit and Pindyck, 1994).

For most policies and some environmental problems, particularly those with more limited time horizons, policy costs are better understood and subject to less uncertainty than are the benefits. Cost functions can also exhibit non-linearity. For example the cost of an incremental reduction in emissions rises rapidly as the emission level becomes very low. However cost functions do not have the 'tipping point' problem.

There are, however, other problems in some policy areas, those with long time horizons, especially related to environmental problems that entail serious cost uncertainty. Pindyck (2009) uses global warming as an example. While carbon tax may be the preferred instrument for reducing carbon dioxide (CO_2) emissions, it is difficult to assert the size of the tax for the reduction of the CO_2 emissions to a target level. The tax-induced price change has different impacts on demand for fossil fuel in different sectors (e.g., transportation versus residential heating). The effect of price change on fossil fuel demand in any sector in turn depends on the long-run price elasticity of energy demand in the sector, and the long-run elasticity of substitution between fossil and non-fossil energy sources. There is a reasonable understanding of energy demand elasticities, but an unclear knowledge of the long-run elasticity of substitution between fossil and non-fossil energy sources. The ability to substitute depends on the cost and availability of alternatives (and the cost will in part depend on its environmental impact). The technological changes determine the extent of substitutability over the next twenty or fifty years from now, which is hard to predict at the present time.

Uncertainty over discount rate

Interest rates are weak or insignificant determinant of investment demand within conventional economic frameworks. A reduction in the discount rate makes the future more important relative to the present. This increases the value of investing (the expected present value of the stream of benefits) and the value of waiting (the ability to reduce the prospects of future losses). The net effect is weak and even ambiguous (Dixit and Pindyck, 1994). However uncertainty about the future path of the discount rate is more crucial for investment than the level of discount rate.

Uncertainty over discount rates has impact on the choice of the effective rate. Uncertainty over future discount rates makes the effective discount rate *lower* than any expected future rate. Recent studies show that discount rate uncertainty reduces the effective discount rate that should be used for policy evaluation (Pindyck, 2009). While these studies do not provide a clear answer, they show that the correct rate should decline over a given time horizon and that the rate for the distant future is most likely well below two percent, which is lower than the rates often used for transport and environmental cost-benefit analysis. Thus, costly environmental policies with benefits long from now may indeed be justifiable.

3.1.2 Policy uncertainty

Governments can create uncertainty by generating an expectation of policy change or by not taking a position on an emerging regulatory framework. Policy uncertainty can have significant effect on investment decisions. Hassett and Metcalf (1999) examine the impacts of policy uncertainty on investment decisions using a real option framework and show that these uncertainties reduce irreversible investments.

3.2 Path dependency and lock-in effect

Dixit and Pyndick (1994, p. 16) define path dependency as a situation where “the current state of the underlying stochastic variable is not enough to determine the outcome in the economy; a longer history is needed. The economy is path dependent.” Path-dependency means that the sequence of historical events influences future possibilities (Kaijser, 2005).

The traditional understanding of long run equilibrium paths of development as well as of equilibrium product market development has been long challenged. David (1985, 1988), Arthur (1989, 1990, and 1992) and Leibowitz and Margolis (1995) have provided background by defining and discussing the issue of path dependency and its implications for future actions[7]. They rely on increasing returns to show that there is an array of possible equilibrium solutions to identical economic problems and for that there is a possibility that the prevailed solution to be suboptimal[8]. The prevailing economic outcome in terms of product type, industry, institutions, or location can itself be a product of some inconsequential and random event. Through the process of increasing returns, a first mover gets advantage over other possible outcomes even if the latter happen to be more economically efficient. Under diminishing returns, static analysis is sufficient; the outcome is unique, insensitive to the order in which choices are made, and insensitive to small events that occur during the formation of a market. Under increasing returns however, static analysis is no longer enough and multiple outcomes are possible.

The properties of increasing returns are non-predictability of the outcome and potential inefficiency of outcome. A dynamic approach adds new properties of inflexibility (path-dependency), in that allocations gradually rigidify, or lock-in, particular structures. The dynamics thus take on an evolutionary flavour. In summary these properties are:

1. Multiple equilibriums. The outcome is not unique and predictable.
2. Possible inefficiency. The outcome may not be the best (under some economic welfare measure)
3. Lock-in. Once a solution is reached, it is difficult to exit from.
4. Path-dependence. The early history of market shares—in part the consequence of small events and chance circumstances—can determine which solution prevails.

Arthur (1989) suggests that not only it is not possible to predict the outcome from usual knowledge of supply and demand functions, and it is not easy to change from a lock-in by standard tax or subsidy policies. Non-convexities and positive feedback mechanisms are now central to modern theories in international trade theory, growth theory, the economics of technology, industrial organisation, macroeconomics, regional economics, economic development and political economy (Arthur, 1994)[9].

3.2.1 Sources of increasing returns in the transport sector

The most important sources of increasing returns in the transport domain are:

[7] See SYNOPSIS: Chronology of important papers on increasing returns by Paul Krugman http://www.pkarchive.org/

[8] The literature on increasing returns and positive feedback dates back to 1920s and 1930s. Self reinforcement in this literature goes under different labels; increasing returns, cumulative causation, virtuous, vicious circle, threshold effect and non-convexity.

[9] Arthur also argues that increasing returns is not yet widely applied in environmental economics and public economics, the two areas of economics that are central for environmental policies and other externality problems involving competing technologies such as competition between transportation modes and on the choice of economic instrument for securing policy objectives.

1. *Network externality* results when one consumer's demand for a product or service depends on how many other consumers have access to the service (Katz and Shapiro, 1985). When a network has few subscribers, the average cost is high and the externalities small. As the number of subscribers grow the cost decline but the utility of each subscriber rises. The concept of critical mass focuses on the relationship between cost and utility and it depends on the nature of the good. Unless the size of a network increases so that rising utility comes into balance with declining cost, the market can't take off on its own. Government or the producer can intervene (through subsidy or regulation) to allow the size of a network reach this critical mass.
2. *Supply externalities* describe the relationship between the diversity of offered services and the network's size (Tirole, 1998). Basically these are related to the compatibility problem.
3. *Learning-by-doing* (Rosenberg, 1982; Atkinson and Stiglitz, 1969). This externality arises when the more a technology adopted, used and known, the more it will be improved. Since producers expect that technology to dominate, through investments they contribute to the improvement of the technology, as in any sell-fulfilling expectation process.
4. *Economies of scale* The cause of economies of scale is mainly the existence of high fixed costs that are independent of the output volume (costs of infrastructure, of R&D, etc.). As output increases, fixed costs are shared by a larger number of units that induces a decrease of the average cost. There are other causes of increasing returns to scale, such as organisational elements, since specialisation, reengineering of production processes and the use of sophisticated means of financing are not feasible beyond a minimum size of production. The crucial result of economies of scale is that marginal cost is always lower than the average cost.
5. *Increasing returns to information* come from the fact that the more a technology is used, the better it is known and uncertainty is reduced in favour of the dominant technology. Most often the risk involved by R&D expenditures undertaken to bring incremental innovations to an existing technology is lower than the risk involved in the development of a new and unknown technology. Risk aversion under these conditions further induces a firm to seek short term financial performance. This leads firms to undertake projects resting upon less risky techniques.
6. *Technological linkages* describe the development of products and sub-techniques that generate increasing returns to adoption (insofar they are representative of the whole industry with regard to vertical integration aspects).

3.2.2 Path dependency; alternative models

Gaviria (2001) provides a review of different modelling techniques in order to capture path dependency and lock-in effects. Different versions of deterministic and stochastic models with positive feedbacks are described in this literature review. Multiple equilibrium and path dependency are common properties of all these models. Potential inefficiencies are also a property of these models; nothing in them guarantees that the best equilibrium—provided that there is one—will be selected. Moreover, once equilibrium is reached, it is difficult to exit from. The modelling approach can determine how the short- medium- and long- run properties of a system can be altered by initial conditions. Arthur (1989) and David (1985, 1988) approach the very long-run properties of systems by slightly altering initial conditions. Dixit and Pyndick (1994) suggest a more moderate path dependency where short- and medium-term evolution can be affected by initial condition.

Locations of stores are also good illustrations of the power of historical accident in shaping locations (see Krugman, 1991a, 1991b, 1991c). The emergence of Santa Clara county, California (Silicon Valley) as the centre of the computer industry and the emergence of the so-called edge cities (Garreau, 1992) can also be explained along the same lines; small accidents start a cumulative process in which the presence of a significant number of firms and workers at a particular location draws even more firms and workers, and so on *ad infinitum*.

3.2.3 Path dependency and institutions

While most often lock-in effects are discussed in the context of technological change, it has been extended to other situations that exhibit path dependency. In fact path dependence is a key element in North's (1990) theory of institutional change. According to North the path of institutional change is shaped by the lock-in that comes from the symbiotic relationship between institutions and the organisations that have evolved as a consequence of the incentive structure provided by those institutions.

Path dependencies are related to historical, political and institutional factors that constrain and mediate the choice and implementation of novel control practices. These have been increasingly used as an analytical lens in policy studies.

3.2.4 Exit from lock-in

Exit from an inferior lock-in in an economy depends very much on sources of the self-reinforcing mechanism. It depends very much on the degree to which the accumulated advantages by the inferior equilibrium are reversible or transferable to an alternative one.

When learning effects and specialised fixed costs are the source of reinforcement, usually advantages are not transferable to an alternative equilibrium. Repositioning the system is then difficult. Reversing the situation may require substantial subsidy. Capital assets are not easily transferable or reversible.

Exit from lock-in arises through gradual progress and major innovations, but also through what Gaviria (2001) formulates as a change in 'fundamentals', self-fulfilling prophecies and random mutations. Under all these models that describe exit from lock-in, once the transition gets started, the move to a new equilibrium will happen quickly.

Changes in fundamentals: Changes in fundamentals relate to changes in technology (or preferences) that lead to changes in behaviour that usually involve sudden shifts. Krugman (1996) provides the example of the two video-playing technologies: VCR and DVD. VCR was a dominant technology; stores mostly carried VCR and most had VCR players. Yet it was an inferior technology compared with DVD. The improvements in laser technology gradually increased DVD and caused the critical-mass curve to shift. Eventually, everybody switched to the laser technology and the lock-in to the tape technology came to an end.

Self-fulfilling prophecies: Self-fulfilling prophecies refers to changes in behaviour of people based on their expectations of changes in other people's behaviour. If most individuals come to believe that everybody is willing a change, there will be a mass exit from the current equilibrium without any change in fundamentals. According to Krugman (1991b), the role of expectations is greater, the higher people weight future income streams, the higher the extent of the external economies involved, and the less costly it is to make the change (e.g., to relocate a new suburban development is arguably more costly than to change a convention).

Random mutations: The assumption under random mutations is that individuals experience independent random mutations. People switch to alternative activities every once in a while without apparent reason. Now, if enough individuals mutate simultaneously, the current equilibrium may be subverted. This argument applies only to small populations because when populations are large the expected time to upset the current equilibrium is not reasonable in any economic context. And lock-in is no longer an issue when mutations are present because the system will spend some time in different equilibrium.

3.2.5 Path dependency: the example of the "car system"

The development of dependence on the car is examined in the context of increasing returns—such as network externalities encompassing several interrelated networks, supply externalities, learning-by-doing, economies of scale, increasing returns to information, and technological linkages, each with its own dynamics and critical mass that have created a path-dependent system.

There are many positive feedbacks that have determined the co-evolutionary interdependence between the car and its supporting infrastructures. The recognition of the complexity of the system is important for many transport policies. Similar feedbacks are significant for the take-off of alternative personalised transport (APT). There is a demand for a systems approach to understand the challenges of creating an APT self-sustaining market (Welch 2006, Ramjerdi, *et al*, 2009).

The massive use of motor vehicles shaped, directed and augmented the structural transformation of urban and rural America in the 1920s. In turn the structure guaranteed its dependence on motor vehicles by its further growth. The history of the development of the internal combustion engine (ICE) technology in Europe is different from US. Although there are differences and the particularities of the dynamics of the system in any particular country, some generalities apply to the car system in most of the developed world.

- The car has remained the most important durable goods in the economy. Market research indicates that after a house, a car is the most important purchase in the life of a person or a household.
- The early establishment of the used car market was necessary for the promotion of cars a durable goods and crucial for the expansion of the car market.
- The car market, covering both new and used cars, covers a wide range of price and attributes that satisfy a significant proportion of the socio-economic spectrum.
- Car industries are characterised by economies of scale and scope
- The car market has created different networks that are essential for its existence. Network economics characterise many part of the car system.
    - The most obvious of these are the different levels of road networks that have been designed, regulated and operated around the dimension and performance of present car technologies with respect to speed, acceleration, safety, etc. These road networks are integrated systematically and tightly, literally defining patterns of accessibility.
    - The filling stations, repair shops and dealers for the sales of new, and more importantly, used cars are other examples of networks that have evolved around car and their present technologies and are crucial support networks.
    - Another is connected to parking places, again an infrastructure which has been evolved around the delineation’s of present car’s technology.
- Co-evolutionary development of bureaucracies and institutions with the development of the car system that has enhanced the path dependencies.

There are many other networks that have been developed with the development of car market, which have similar properties. One is the parking system; public and private. Other important supporting networks are filling station, repair shops, dealers, etc. Hence the ICE system can be viewed in the context of its increasing returns. Network externalities encompassing several interrelated networks, supply externalities, learning-by-doing, economies of scale, increasing returns to information, and technological linkages, each with its own dynamics and critical mass have created a path-dependent system.

3.3 Summary and conclusions

In this chapter two interpretations of irreversibility that are relevant to OPTIC are proposed. One interpretation is when a return to the status quo is impossible or extremely difficult, at least on a relevant timescale. This is the interpretation the environmentalists relate to. The relevance of irreversibility is its association with the magnitude of the damage. An alternative interpretation sees irreversibility in terms of sunk cost, corresponding to the definition in economic literature on options theory. Those costs that cannot be recovered totally are sunk costs. With either of these interpretations, *irreversibility only matters if there is uncertainty*. Irreversibility can also arise due to government regulation or institutional arrangements.

There are usually important irreversibilities associated with environmental problems. These irreversibilities can arise not only with respect to environmental damage itself, but also with respect to the costs of adopting policies to reduce the damage. Regulation that reduces one environmental risk might well increase other environmental risks. Efforts to reduce the dangers associated with fossil fuels, for example, may lead to increased dependence on other sources of energy that have economic as well as environmental costs. We are facing irreversibilities, not irreversibility.

Over long-term horizons, unpredictable technological change, changes in land use, population shifts, changes in values and preferences, etc., make the uncertainties over policy's costs and benefits considerably greater. Uncertainties over benefits and costs are related to the parameter uncertainty, but also to the form of uncertainty over the shapes of the benefit and cost functions. Furthermore discount rates are inherently uncertain, and a long time horizon makes such uncertainty especially important. These uncertainties have major consequences for the conventional models that assume stability of parameters over time, such as those associated with benefits, costs and discount rate. The quantitative models that have been addressed in Deliverable 2 are all of this nature. These points suggest that the traditional methods applied for policy appraisal are often inaccurate and can result in biased policy appraisal processes.

Governments can create uncertainty by generating an expectation of policy change or by not taking a position on an emerging regulatory framework. Policy uncertainty can have significant effect on investment decisions.

Path-dependency means that the sequence of historical events influences future possibilities. With the acknowledgment of path dependency, the traditional understanding of long run equilibrium paths of development is contested (i.e., the traditional models used for transport demand analysis are inadequate for handling these issues). An important cause for path-dependency in an economic domain is increasing returns. The most important sources of increasing returns relevant to the transport domain are: network externalities, supply externalities, learning-by-doing, economies of scale, increasing returns to information and technological linkages. The properties of increasing returns are: multiple equilibriums and possible inefficiency of outcome, path-dependence and lock-in. It is emphasised that traditional models in economics are not appropriate for predicting outcomes in complex, open systems and it is far from easy to escape from a lock-in situation by following standard tax/subsidy policies. Indeed, exit from an inferior lock-in situation depends very much on sources of self-reinforcing mechanisms and the degree to which the accumulated leads by the inferior equilibrium are reversible or transferable to an alternative one. When learning effects and specialised fixed costs are the source of reinforcement, usually advantages are not transferable to an alternative equilibrium. Repositioning the system is then difficult and may require considerable financial resources as capital assets are not transferable or reversed.

The development of the car system is examined in the context of its increasing returns of adoption. Network externalities—encompassing several interrelated networks, supply externalities, learning-by-doing, economies of scale, increasing returns to information, and technological linkages, each with its own dynamics and critical mass can result in a path-dependent system. The recognition of path dependency and lock-in effect are important for many transport policies. Similarly, increasing returns are significant for the take-off of alternative fuel and vehicle technologies and hence associated policies.

4 Integration of risk and uncertainty in the design of policy measures (*ex-ante*)

Transport economics has extensively studied impacts of policy interventions, such as changes in supply of or demand for transport services (see for example Small and Verhoef, 2007). Numerous economic assessments of transport policy interventions and their likely effects have been made, often with a focus on finding theoretically optimal solutions. However it is recognised that due to factors such as risk and uncertainty and irreversibility, it is not always possible to completely predict target group responses with conventional economic models.

To varying degrees, most policies share three important characteristics: i) they are partially or completely *irreversible*, ii) there is *uncertainty* over the future benefits of the policy and iii) there is flexibility about the *timing* of project (Dixit and Pindyck, 1994). The traditional theory for the evaluation of policies does not recognise the important quantitative and qualitative interaction between irreversibility, uncertainty and timing. Policy evaluation boils down to deciding whether the benefits of a project or policy are larger than the costs. In the neoclassical approach the present values of benefits and costs, that usually occur in the future, are calculated using a discount rate, and the difference between the present value and the present value of the costs—the net present value or 'NPV'—indicates the desirability of the projects. When several alternative policies exist, the one with the highest NPV should be selected. The problem is in reality more complicated, especially when costs and benefits of a policy occur over long time horizons and due to risk and uncertainty, and irreversibilities. Most investments and environmental policies are in this category.

This chapter briefly presents option theory and its wide application to the policy problems associated with risk, uncertainty and irreversibility. Three important policy areas in an EU as well as a national context are discussed: alternative fuels and vehicles, infrastructure investment, and environmental problems.

4.1 Option theory

When there is uncertainty about the timing and likelihood of an irreversible loss, one should be willing to pay a sum—the option value—in order to maintain flexibility for the future. The option might not be exercised if it turns out that the loss is not a crucial one. But if the option is purchased, policy makers will be in a position to prevent the loss if it turns out to be large. Alternatively, they might obtain the right to scale back a project, to abandon it, to expand it, or to extend its life. Option theory has countless applications outside of the domain of investments. Numerous researchers have applied option theory for environmental risk regulation and evaluations (see Sunstein, 2005).

Arrow and Fisher (1974) and Henry (1974) demonstrate that the ideas of uncertainty and irreversibility have considerable importance to the theory of environmental protection. They use a linear net benefit function and an all-or-nothing choice situation and show that it will be optimal to delay or reduce investment. Arrow and Fisher give the example of the alternative actions of development or keeping a wilderness. They argue that if development produces “some irreversible transformation of the environment, hence a loss in perpetuity of the benefits from preservation,” (Arrow and Fisher, 1974; p. 313) then it is worth paying for the option to wait to acquire the missing information. Their proposal is that the expected benefits of an irreversible decision should be adjusted to reflect the loss of options it involves. Other economists have made important contributions to this subject by extending the theory for nonlinear benefit function and continuous choice and temporal resolution of uncertainty. There have also been contributions to the subject with techniques such as stochastic optimisation[10].

There are numerous examples of the application of options theory in the literature in the context of ‘long-term effects’. The area of technology adoption under uncertainty and irreversibility has received ample attention[11]. So has the problem of infrastructure investment under demand uncertainty and land allocation problem with economic and environmental uncertainty[12].

4.2 Alternative fuels and vehicles technologies (AFV)

The creation of a self-sustaining market for AFV is very costly for society. It involves consumers, many industries, institutions and considerable investments including those related to infrastructure. ‘Irreversibility’ is highly relevant in this process. The different stakeholders in these different interacting markets face decisions under uncertainty, including in their relation to governments policies. The examples of these policies are taxations, subsidies and regulatory measures related to fossil fuels and conventional cars and alternative fuels, as well as the necessary measures related to the supporting infrastructures, and industries. The problem of investment under uncertainty has been extensively studied in the literature with a focus on adaptation of technologies, effectiveness of the governments’ environmental policies, processes of technological change (see e.g., Stavins *et al*., 2002).

[10] See for example Dixit and Pindyck (1994), Dixit and Pindyck (2000), Epstein (1980) Freixas and Laffont (1984), Hanemann (1989), Kolstad (1996), Ulph and Ulph (1997), Gollier *et al* (2000).

[11] A firm faces a trade off between investing in a superior technology in order to produce more efficiently from early on and large sunk costs have to be paid for the decision (Fudenberg and Tirole 1985). Dixit and Pindyck (1994) combine the Fudenberg-Tirole framework with the theory of investment under uncertainty and allow the firm’s profit flow to be stochastic. Huisman and Kort (2000, 2003) extend Dixit and Pindyck model by incorporating an additional technology that becomes available at an unknown point of time in the future. van Soest *et al* (2000) have analysed energy investments’ using option theory to address uncertainty and irreversibility. Their model shows that a firm’s responses to energy price increases and decreases are not symmetric. The literature on the potential causes of asymmetric responses to energy price increases and decreases has focused on the importance of irreversibility that is intensified by uncertainty. If adjustments are costly and the future is uncertain, the option value of waiting increases.

[12] Bosetti and Messina (2001) apply options theory to land allocation problems. They include both environmental and economic uncertainty in their model and two types of irreversibility: sunk costs associated with investment in developing decisions, environmental and social costs due to environmental degradation, and sunk costs associated to environmental regulation and conversation. They integrate decision analysis techniques and option theory to evaluate development versus conservation opportunities.

Meanwhile governments need to make the 'right' choice among technologies and, like other stakeholders, face uncertainties and risks. What are the 'correct' sets of policies and how should the policies be phased in and out? How should the government address the choice among technologies? And what are the variables/factors that need to be taken into consideration in this decision-making?

Another equally if not even more costly solution for society is for government to support the take-off of an AFV technology that could prove to be not 'good enough' or as bad compared to internal combustion engines. Environmental concerns are both local and global and the alternative fuel technologies need to respond to both demands. The adverse environmental impacts of production and use of alternative fuels, locally and globally, in a life cycle perspective could be significant. Take the example of alternative biofuels with wide range of local and global environmental impacts (Concawe 2007).

'Getting prices right'—in the sense of choosing the desired (socially optimal) path, or scenario—and driving markets along a dynamic pattern of feasible technological change through externality taxation (or emissions permits) may not be easy. A single price on greenhouse gas emissions, or a subsidy on greenhouse gas abatement, might not discriminate effectively between different technologies at different stages of take-off. Arthur (1990, p. 129) points out to the difficulties of such policy problem and states that "the question of using well-timed subsidies to prevent the adoption process 'tipping' and shutting out (beneficial) technologies has not yet been looked at. But its structure – that of artificially stabilising a naturally unstable dynamical process – is a standard one in stochastic feedback control theory."

4.3 Transport infrastructure

There is a growing concern about the inadequacy of the traditional approach to transport infrastructures. And there is an increasing recognition that the scope of project evaluation should be extended to account for uncertainty, irreversibility, and path dependency—in particular in response to the challenges of sustainable development. While transport is a key to economic development, it also contributes a range of societal and environmental costs.

Urban and regional transport infrastructures may have many rebound effects that are long lasting and reinforce 'lock-in' effects. A move to another equilibrium that is potentially more efficient than the present might require substantial effort. For example, private motor vehicle transport and public transport are, to a degree, substitutable. Each mode is self-reinforcing, meaning that the more it is used, the more funds become available for investment and improvements in that mode. As a result of the improvements, the mode attracts even further users. Then one mode may achieve dominance at the expense of the other. Reversing the situation may require substantial capital investment and/or targeted subsidies.[13]

[13] This example is provided by Arthur (1990)

Another important setting that reinforces path dependency of the road system is caused by the extent of the development of the road network compared with rail network, especially in urban environments. This situation favours the extension of the road network compared with the rail network. The extension of the road network in this setting most often seems marginal, with low uncertainty associated with cost, demand or discount rate and often the projects can be completed within relatively short time. Thus the extension of road network almost always compares favourably with rail and even passes some of the additional hurdles imposed by the requirements of real options frameworks. Extensive subsidies to the alternative mode might be desirable in the long run.

The uncertainties and risks associated with an infrastructure investment problem are numerous, characterised by multiple interactions and broad consequences for the regions, environments and societies they are intended to serve. Often, the costs and benefits of transport projects are not distributed equitably, including those related to environmental impact. Evidence not only casts doubt on the ability to deliver transport infrastructure on time and within budget (Flyvbjerg *et al* 2003), but also their projected range of urban and regional development impacts (Broecker *et al* 2003). Flyvbjerg (2009) examines about 260 major infrastructure projects and summarises their characteristics as follow[14] :

- They are inherently risky owing to long planning horizons and complex interfaces.
- Technology and design are often non-standard.
- Decision-making, planning, and management are typically multi-actor processes with conflicting interests.
- Often there is ‘lock-in’ or ‘capture’ of a certain project concept at an early stage, leaving analysis of alternatives weak or absent.
- The project scope or ambition level will typically change significantly over time.
- Statistical evidence shows that such unplanned events are often unaccounted for, leaving budget and time contingencies sorely inadequate.
- As a consequence, misinformation about costs, benefits, and risks is the norm throughout project development and decision-making, including in the business case.

The result is cost overruns and/or benefit shortfalls during and following project implementation, respectively. Flyvbjerg (2009) draws on three main types of explanations to account for cost overruns and benefit shortfalls in major infrastructure projects: technical, psychological, and political-economic. Technical explanations account for cost overruns and benefit shortfalls in terms of imperfect forecasting techniques, inadequate data, honest mistakes, inherent problems in predicting the future and lack of experience on the part of forecasters. This is the most common type of explanation of inaccuracy in forecasts. Technical error may be reduced or eliminated by developing better forecasting models, better data, and more experienced forecasters, according to this explanation. Psychological explanations account for cost overruns and benefit shortfalls in terms of ‘optimism bias’ (see Kahneman and Tversky, 1979; Kahneman and Lovallo, 1993; and Lovallo and

[14] Typically at costs per project from around a one hundred million dollars to several billion dollars

Kahneman, 2003). The differences between subjective and objective evaluations of risk and uncertainty by decision makers are the key in making a decision contrary to a rational weighting of gains, losses, and probabilities. And political-economic explanations see project planners and promoters as deliberately and strategically overestimating benefits and underestimating costs when forecasting the outcomes of projects. Strategic misrepresentation can be traced to agency problems and political and organisational pressures—for instance, competition for scarce funds (cf. Chapter 2).

Strand and Miller (2010) address the options of scaling down energy consumption and carbon emissions in the future and the costs of these policies. They focus on bulky infrastructure investments, such as investment on road infrastructure, sunk at an initial time of decision, that 'tie up' energy consumption for a long future period and make it more costly to reduce emissions later. With expected energy and environmental costs continually on the rise, inherent biases in the selection processes for infrastructure investments lead to excessive energy intensity in such investments[15].

The potential reasons for bias include: systematic under-valuation of future energy costs; failures to incorporate true (current and future) social carbon emissions costs; and excessive discounting. It is increasingly recognised that the presence of such an established infrastructure may form a major *ex-post* obstacle to effective mitigation policy, for a long future period. This is the case regardless of whether the *ex-ante* infrastructure investment is 'optimal' or not (see for example Ha-Duong, 1998; and Shalizi and Lecocq, 2009).

Strand and Miller warn that great care must be taken when choosing the energy intensity of the infrastructure at the time of investment[16]. They further address the two ways carbon emissions can be reduced post-investment: retrofitting the infrastructure, or closing it down[17]. Their analysis suggest optimally exercising the retrofit option, when it is available, reduces *ex-ante* expected energy consumption relative to the no-option case. Total energy plus retrofit costs can also be substantially reduced, more so, the larger is *ex-ante* cost uncertainty.

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[15] See also by Brueckner (2000), Gusdorf and Hallegatte (2007a,b), and Glaeser and Kahn (2008) for the effects of infrastructure choice on energy consumption and CO2 emissions.

[16] "Optimal" infrastructure choice here is defined from the viewpoint of a social planner. The optimality is from a particulate (local, national or global level) point of view and relates to that level's perspective and prices, costs, discount rates etc. In a climate policy context such a view tends not to be correct, even when formulated at the national level, since a global view is needed, with the marginal externality cost at the *global* level. Local decision makers are not likely to behave this way. Strand and Miller also discuss the concept of a "low-carbon society" and ways to achieve it (see Strachan *et al*, 2008a, 2008b; and Hourcade and Cerassous, 2008). The overriding idea is that achieving a society with low GHG emissions (necessary for efficiency in the long run) requires a high concern for the design of current infrastructure investment.

[17] A "retrofit" can be interpreted in several ways. One possibility is that alternative sources of energy can be used in the operation of the infrastructure. This interpretation of a potential retrofit option does not imply that retrofit is necessarily an economically optimal choice. There are cases in which exercising the option of retrofit would be prohibitively costly. The availability of the retrofit option also leads to a more energy intensive initial infrastructure choice; this offsets some, but usually not all, of the gains from options for subsequent retrofitting.

4.4 Environmental policies

Uncertainties are greater for many environmental problems and consequently consideration of uncertainty is more important and relevant for policy design and evaluation. Pindyck (2007) address three key complications that are often crucial to environmental policy, but are usually much less significant for most other policy decisions. These complications are first that environmental cost and benefit functions tend to be *highly nonlinear*. The second is that environmental policies usually involve important *irreversibilities*, and those irreversibilities sometimes interact in a complicated way with uncertainty. It was pointed out earlier that there are two kinds of irreversibilities that are relevant for environmental policies, and they work in opposite directions. Policies aimed at reducing environmental degradation almost always impose sunk costs on society. If future costs and benefits of the policy are uncertain, these sunk costs create an opportunity cost of adopting the policy, rather than waiting for more information about environmental impacts and their economic consequences. This implies that traditional cost-benefit analysis will be biased toward policy adoption. On the other hand, environmental damage is often partly or totally irreversible. This means that adopting a policy now rather than waiting has a sunk benefit, that is a negative opportunity cost. This implies that traditional cost-benefit analysis will be biased against policy adoption. The third complication is that, unlike most capital investment projects and most other public policy problems, environmental policies often involve *very long time horizons*. While net present value calculation for an investment rarely go beyond twenty or twenty-five years, the costs and especially the benefits from an environmental policy can extend for a hundred years or more. The problem of climate change is a well known example with long time horizons, but there are also others. The uncertainty regarding costs and benefits of policies increases with the time horizon. A long time horizon also makes discount rate uncertainty much more important. Uncertainty over future discount rates has an important implication for the choice of discount rate that we should use in practice—it makes that rate *lower* than any expected future discount rate.

4.5 Implications for policy design

How important are these irreversibility issues and what are their implications for policy? The answers depend on the nature and extent of the uncertainties over costs and benefits, and how those uncertainties are likely to get resolved over time. The greater the current uncertainties and the greater the rate at which they will be resolved, the greater will be the opportunity costs and benefits associated with policy adoption (Dixit and Pindyck, 1994, Pindyck, 2007). Irreversibility can interact with uncertainty to affect current policy, sometimes making it more and sometimes less 'conservationist.'

Uncertainties over benefits and costs can affect policy design in at least three fundamental ways. First, they can affect the optimal choice of *policy instrument* that is whether pollution is best controlled through a price-based instrument (e.g., an emissions tax) or a quantity-based instrument (e.g. an emissions quota). Second, they can affect the optimal *policy intensity*, for example, the optimal magnitude of the tax or the optimal level of abatement.

Third, they can affect the optimal *timing of policy implementation* that is whether it is best to put an emissions tax in place now or wait several years (and thereby reduce some of the uncertainty) (see Pindyck, 2007).

The consequence of uncertainty for the optimal choice of policy instrument has been studied extensively, beginning with the seminal work by Weitzman (1974), who showed that in the presence of cost uncertainty, the relative slopes of the marginal benefit function and marginal cost function determines the choice of instrument; a price-based or a quantity-based[18]. In a world of certainty, either instrument will be equally effective. If there is substantial uncertainty and the slopes of the marginal benefit and cost functions differ considerably, the choice of instrument can be crucial[19]. Later studies suggest that, in the presence of uncertainty, policies that combine both instruments (hybrid policies) are generally more efficient than a single instrument (e.g., Roberts and Spence, 1976; Weitzman 1978, Pizer, 2002 and Jacoby and Ellerman, 2004). The optimal design of a hybrid policy depends not only on the shapes of the benefit and cost functions, but also on the nature and extent of the uncertainties. Uncertainties and lack of knowledge of the shapes of the benefit and cost functions means that policy design will be suboptimal at best. Mandell (2010) argues that in an EU context the optimal design will depend on the relative cost structures within and outside the transport sector and the optimal regime for the transport sector is a hybrid system, combining a cap-and-trade and an emission tax.

Uncertainties over benefits and costs can also affect the optimal policy intensity—that is the size of an emissions tax or the amount of abatement that is needed. Without irreversibilities, uncertainty usually leads to *lower* policy intensity. Uncertainty also affects the optimal timing of policy implementation—but only when there are sunk costs associated with implementing the policy, and/or irreversibility is associated with environmental damage. Depending on a particular situation, it may be optimal to postpone the implementation of a policy until there is more information on benefits and costs, or to accelerate the implementation to avoid irreversible damage (as with climate change).

In the context of environmental problems, there are very few policy problems for which the effects of irreversibilities have been studied in any detail (Pindyck, 2007). The problem that has received the most attention is anthropogenic climate change. While there is a good sense of the irreversibilities involved in this issue, the uncertainties are considerable. There is no clear understanding of the importance of irreversibilities and their consequence for policy. The climate-economy models that are used to determine the optimal abatement policy include numerous simplifying assumptions, and different sets of simplifying assumptions

[18] If the marginal benefit function is steeply sloped but the marginal cost function is relatively flat, a quantity-based instrument (e.g., an emissions quota) is preferable: an error in the amount of emissions can be quite costly, but not so for an error in the cost of the emissions reduction. The opposite would be the case if the marginal cost function is steeply sloped and the marginal benefit function is flat.

[19] Weitzman's original result has been extended in a number of directions. For example, Stavins (1996) showed that a positive correlation between marginal benefits and marginal costs pushes the optimal choice towards a quantity instrument. Often, however, there is no need to choose exclusively between a price and a quantity instrument.

have led to quite different results. Those studies that ignore possible catastrophic impacts suggest that we should move slowly. Those studies that consider the possibility of catastrophic impacts suggest a more stringent emissions policy, but there is no empirical evidence for the catastrophic impacts assumed in these studies.

4.6 Summary and conclusions

Most policies share three important characteristics in varying degrees: i) they are partially or completely *irreversible*, ii) there is *uncertainty* over the future benefits of the policy and iii) there is flexibility about the *timing* of project (Dixit and Pindyck, 1994). The traditional theory for the evaluation of policies does not recognise the important quantitative and qualitative interaction between irreversibility, uncertainty and timing. Policy evaluation boils down to deciding whether the benefits of a project or policy are larger than the costs. The problem is in fact more complicated, especially when costs and benefits of a policy occur over long time horizons and due to risk and uncertainty, and irreversibilities. Most investment and environmental policies are in this category. Policy adoption is rarely a now or never proposition. In most cases it is feasible to delay action and wait for new information. With uncertainties and irreversibilities, there is leeway about the intensity of the policy (for example the size of fee on GHG emissions) and the timing of policy adoption (for example how to change the fee on GHG over time) with significant effect on the optimal policy adoption path (see Dixit and Pindyck, 1994; Pindyck, 2009). Option theory provides support for decisions under such circumstances. There are numerous examples of the application of options theory in the literature especially in the context of 'long-term effects'. The areas of technology adoption, transport investment and land development have received ample attention.

Three important policy areas where uncertainties and irreversibilities are potentially great in the transport domain with particular relevance to the EU have been briefly reviewed: alternative fuels and vehicles, infrastructure investments and environmental problems. The purpose of the reviews has been to illustrate the inadequacies of the traditional quantitative models for the evaluation of policy formulation in each of these areas (see Deliverable 2; DLR and KIT, 2010). A further purpose of the review is to emphasise the need for flexibility in planning when uncertainties and irreversibility are present.

How important are these irreversibilities and what are their implications for policy? The answers depend on the nature and extent of the uncertainties over costs and benefits, and how those uncertainties are likely to get resolved over time. The greater the current uncertainties and the greater the rate at which they will be resolved, the greater will be the opportunity costs and benefits associated with policy adoption (Dixit and Pindyck, 1994, Pindyck, 2007).

5 Remedial actions through ex-post measures

In highlighting the importance of integrating risk and uncertainty into the policy-making process, this deliverable has thus far extensively discussed *ex-ante* considerations of irreversibility, path-dependency and lock-in effects. In this chapter, we build on these considerations to examine how the conceptual policy packaging framework outlined in Deliverable 1 can offer *ex-post* support to policy-makers seeking to understand and, if necessary, address policy interventions' effectiveness, efficiency and propensity for unintended effects. First, we focus on the importance of comprehensive monitoring activities—the processes by which policy interventions' effectiveness, efficiency and propensity for non-intentional effects are observed and recorded for the purpose of regulation or control. Second, we reengage with the substantive procedural components of policy packaging outlined in Deliverable 1 and point to a range of potential causes of package sub-optimality. Finally, extending this approach, we discuss the potential scope and character of *ex-post* remedial actions that may be required to improve package performance.

5.1 *Ex-post* monitoring

Clearly, high-quality monitoring is vital for effective engagement with the issues of risk, uncertainty and non-intentional effects outlined in previous chapters. Indeed, monitoring represents the principle mechanism by which one can gain insight and understanding about the effects (both positive and negative) of a policy intervention on the dynamics of a particular socio-technical system (e.g. the impact of a congestion charge on congestion levels). Currently, various monitoring practices are evident in the European transport policy community. For the purposes of this Deliverable, these can be conceptualised in terms of an '*ex-post* monitoring continuum'. As with all conceptual frameworks, this continuum is highly stylised, and designed to facilitate conceptual understanding rather than to accurately represent the state of monitoring practices *per se*. Nevertheless, we can broadly conceive of five 'points' on the continuum: (1) situations where no monitoring takes place; (2) situations where basic 'rhetorical monitoring' takes place; (3) situations where more quantitative monitoring takes place; (4) situations where data from (3) are subject to detailed analysis; and (5) situations where analysis from (4) supports consideration of policy implications and remedial actions. Given the purpose of Deliverable 3, and the OPTIC project more widely, we are naturally interested in exploring cases that are illustrative of points (4) and (5). However, it is also worth discussing examples of (2) and (3).

(2) Rhetorical monitoring

This monitoring approach basically consists of studies that seek to advertise the success of a project, often for a public audience. Evidence from such monitoring may be cited as a means of establishing an intervention as a 'good' or 'best practice', with policy actors seeking to benefit from the 'symbolic capital' that this provides (Bordieu, [1979] 1984; see also Vettoretto, 2009). A good example of rhetorical monitoring is provided by Öresundsbro Konsortiet (2009) who describe the impacts of the Öresund bridge—that links Sweden and

Denmark—in terms of traffic development, a common labour market, the housing market, economic activity, tourism and leisure. They argue that developments have been positive in all of these areas and that the success of the bridge was fully established in 2007 when the original traffic forecasts from the opening year were significantly exceeded. In 2009, an average of 19,500 vehicles crossed the bridge per day. Interestingly, since opening, the bridge has been transformed from a bridge for holidaymakers to a bridge for commuters; by 2009 almost 20,400 people commuted to work and to study on the other side, a figure which continues to grow at 20 and 40 per cent per year. Since Copenhagen is perceived as more attractive than Malmö on the Swedish side, the traffic flow is highly mono-directional. About 95 per cent of all commuters travelling on the bridge live in Sweden and work in Denmark. Rail traffic has undergone rapid development, too, with passenger volumes rising from 4.9 million to 11.1 million between 2001 and 2009. Clearly, such monitoring is inevitable given the nature of contemporary transport interventions. However, normatively-speaking, it falls short of the analytical standard required for gaining sufficient *ex-post* understanding of intervention impacts. As Flyvbjerg *et al*. (2008) note, too, actual traffic rates for the bridge were *at times* much lower than those forecasted, illustrating the almost universal phenomenon of overestimating demand and underestimating cost.

(3) Quantitative monitoring

A relatively straightforward *ex-post* monitoring approach consists of studies that seek to identify the impacts of an intervention through quantitative comparisons of the 'before' and 'after' situations. These can either follow pre-planned specifications or function on an *ad hoc* basis and correspond to tools such as traffic counts and high-level surveys. A good example of this approach is Emmerson *et al*.'s (1996) investigation of the impacts resulting from a new 35km section of the A14 dual carriageway in the UK. The traffic data collection involved automatic and manual traffic counting and roadside interviews (including origin and destination confirmation) in the period immediately preceding the opening of the new road and again twelve months later. Various aspects of the new road's impact were considered, but the principle focus was on traffic flows, which were found to be surprisingly high. The explanation given was twofold: route reassignment and induced traffic. A similar approach was used in an impact study of Croydon Tramlink, UK (Copplery *et al*., 2002). Here, the aim of the monitoring was to understand the effect that the new tram system had on travel patterns and wider transport systems. The impact was assessed through *ex-ante* and *ex-post* studies conducted one year apart and comprised of three main elements: home interview surveys, stated preference interviews and cataloguing the characteristics of the transport system. One of the main objectives was to compare the actual usage of Tramlink compared to the *ex-ante* survey in which respondents were asked to indicate how likely they would be to have used Tramlink if it had been available. In Norway, a comparable evaluation approach was followed in the monitoring of eleven different public transport cases ("packages of measures"), where the standard evaluation plan consisted of four main elements: travel surveys with panel selection; surveys among passengers travelling on the new services; registration of area data; and time series data (ticket sales) (Kjorstad and

Norheim, 2005). While such approaches are clearly useful, however, the potential insights buried in the data that they generate risk being overlooked. In essence, this descriptive approach represents a viable means for painting an 'extensive' picture of an intervention's impact, but it falls short as a means of generating 'intensive' insights into the causal mechanisms at work (Sayer, 1992).

(4) Analytical monitoring

Beyond such descriptive data collection, we can note several instances where analysts have opted to undertake detailed data analysis as part of their monitoring activities. Interestingly, as Madsen and Jensen-Buthler (1999) note in the case of the Öresund bridge, such *ex post* analyses have to take into consideration broader causal factors and their interaction. For example, rather than treating changes in traffic flows and changes in regional economic variables independently, *ex post* analysis ought to extend this approach through the use of modelling tools which permit identification of the relative contributions of different causal factors (e.g. bridge construction, the effect of other transport infrastructure investments, broader changes in regional economic activity and natural trends over time).

In this vein, Loop and Perdok (2004), focus on the *ex-post* analysis of the Dutch national programme on traffic congestion. Since 2002, planning authorities in the Netherlands have been obliged to describe their planned policy measures, together with *ex-ante* estimations of costs and outcomes. Subsequently, they are required to report which policy measures were realised, the costs incurred and the actual outcomes reached. One particular package was designed to reduce congestion and consisted of demand management interventions, public transport improvements, use of the hard shoulder as rush hour lane and the provision of additional road capacity. The Dutch National Model System was used to provide *ex ante* estimates of congestion reduction and the *ex post* analysis was undertaken to examine the extent to which the package genuinely influenced congestion levels. In their analysis, the authors focused on the estimate of their impact on 'vehicle hours of delay' and ensured that they accounted for the effects of road construction works, accidents adverse weather conditions, population, car ownership and employment patterns. They concluded that the demand-oriented policy measures had little impact on congestion while traffic management programmes had a significant positive effect. The latter included measures such as rush hour lanes, dynamic route information, ramp metering, traffic signs, speed reduction, speed control and incident management.

In Norway, the Ministry of Transport and Communications authorised the Norwegian Public Roads Administration to carry out an *ex-post* cost-benefit analysis of eight road-building projects. The purpose of this exercise was to evaluate whether the expected benefits from the projects had been achieved and to examine the extent to which the results differed from *ex ante* estimates presented to decision-makers (Kjerkreit *et al*., 2008). In the analyses, only the monetised impacts were taken into account and the same software package was used for both *ex-ante* and *ex-post* exercises. In terms of net present value and benefit-cost ratios, the study found that seven out of the eight projects had resulted in greater benefits than had originally been forecast *ex-ante*. The main sources of variance between the two sets of analysis were found to be related to construction costs, accidents and traffic volumes.

The impact of the large infrastructure project on regional development has also been documented in the case of the Jubilee Rail Line Extension (JLE), which started operations in the autumn of 1999 and connects Green Park to Stratford in London, UK (Jones, 2004). Impact assessment focussed on four criteria: transport impacts and accessibility changes; residential and commercial development, including impacts on land value; employment and impacts on the economy; and impacts on residents and their travel patterns. In order to fully explore the impacts of the Jubilee Line Extension six surveys were conducted before and after the extension was opened. Evaluation of all surveys and their results has shown that expected benefits have been mostly achieved. The JLE has raised land values and property prices and has stimulated fast development. On the other hand, the impact of the JLE on employment and business activity in London has been more difficult to prove. Although the evaluation has shown that the JLE has helped to increase economic activity in parts of the corridor, the real impact of the JLE might have been a shift of economic activity from one location to another rather than an absolute increase in economic activity in London. Finally, it is noted that it may take several decades for the full effect of the JLE on land use patterns and associated travel patterns to be realised.

In a different sense, Chapulut *et al*., (2005) highlight the manner in which the French authorities have sought to monitor the impacts of transport interventions. Historically, the expected impacts of many schemes were determined by relatively narrow cost-benefit analyses that excluded present concerns such as traffic noise, local pollution and greenhouse gas emissions. Thus recent *ex post* monitoring efforts have had two respective purposes. First, analyses have been carried out using the original CBA methodologies in order to evaluate the accuracy of the *ex ante* appraisals, while the second seeks to determine the actual impacts across a broader array of variables.

Anguera (2005) reports on an interesting *ex-post* economic evaluation of the Channel Tunnel, directly linking the UK and French rail networks, which compares 1987 forecasts for passenger and freight volumes in 2002-3 with reported data. In terms of passenger travel, the 1987 forecasts were relatively accurate. With regard to freight, the actual volume moved through the tunnel in 2002-03 was significantly greater than had been predicted. The most significant variable in the cost-benefit analysis, however, was construction cost, which overran by 99% compared to the original 1985 estimate. The major benefits from the tunnel were travel time savings (both passenger and freight) and benefits from fare reduction. However, the analysis did not include environmental impacts or socio-economic impacts such as effects on employment or energy consumption. Overall, the appraisal revealed that the British economy would have been better off had the Tunnel never been constructed, mainly due to the high construction cost, although the influence of this is augmented due to the relatively short appraisal period.

In undertaking such analyses, it can be highly beneficial to complement CBA methods with multi-criteria analyses (MCA). MCA is designed to provide a flexible way of dealing with qualitative effects of transport projects/policies, whereby impacts are weighted depending on their relative importance of meeting the objectives of the projects/policies. One instance of MCA being used to address socio-economic impacts of transport investments and policies is in the EU project TRANSECON (2003), where the long-term effects of implemented large scale infrastructure investments in 13 European case studies were analysed.

(5) Implications and actions

At the top end of the continuum we can find evidence of highly detailed, comprehensive and well-funded *ex-post* monitoring programmes in which the policy implications of analytical observations are recognised and are fed back into the design of policy interventions—either in the form of remedial actions, or in developing related interventions. Transport for London, for example, has invested heavily in *ex-post* monitoring of the London Congestion Charge (LCC). As set out in TfL (2003, pp. 28-29), the organisation closely adheres to an 'Impact Monitoring Strategy', which is founded upon the following five principles:

A) '*Monitoring should robustly detect and characterise the main expected effects of congestion charging'*, which reflects a commitment to comparative analysis of *ex ante* and *ex post* appraisals.

B) '*Monitoring should enable unexpected or unanticipated effects to be determined'*, which is designed to ensure that the monitoring approach remains sensitive to the presence of non-intentional effects.

C) '*Monitoring should seek to understand, as well as measure*', which reflects the need for qualitative methods.

D) '*Monitoring should aim to meet the legitimate needs of all stakeholders for information*', which is designed to ensure that the monitoring process remains democratic, transparent and accessible to a range of individuals, organisations and economic sectors.

E) '*Monitoring should provide best value*', which aims to ensure that the monitoring procedures remain cost-effective.

Evans (2007) summarises the results from several *ex-post* evaluations of the congestion charging scheme. The main inputs have been gained from the comprehensive programme of monitoring of traffic conditions since the charge was introduced in February 2003 and subsequent comparisons of these results with *ex-ante* conditions. The evaluation of the scheme follows the UK Department for Transport's *New Approach to Appraisal* and thus incorporates impacts such as safety, greenhouse gas emissions, accessibility and those relating to the local economy. Costs are treated as capital costs, operating costs and costs to public accounts (i.e. tax revenue). For the LCC, principle costs included traffic management measures, communications and public information on the scheme, systems set-up and management. Overall, the assessment includes Transport for London charge revenues (charges paid by individuals, charges paid by business, operating costs, infrastructure costs);

central government tax losses (fuel duty, VAT on bus fares, VAT on charges); and borough revenues (net parking revenue). Principle benefits related to transport efficiency, which includes travel time, travel time reliability, vehicle operating costs savings and user charges.

In addition to the London Congestion Charge, the Stockholm congestion charging trial (January to July 2006) neatly illustrates how monitoring can inform project development, despite the fact that it occurred *ex-ante* to the main intervention. The objectives of the trial were fourfold: to reduce the number of vehicle passing the congestion-charge zone in peaks periods by 10-15%; to improve the flow of traffic on the busiest streets and roads in Stockholm; to reduce emissions into air in the inner city; to improve the urban environment. The cost-benefit analysis of the Stockholm trial was carried out by the TRANSEK (2006) and was based on measurements of traffic volumes and travel times by car, together with passenger statistics from Stockholm Transport. The analysis focussed on two issues the congestion charging scheme and the expansion of bus services, including the increased number of park-and ride sites.

The CBA showed that if the congestion charging system was not continued, the socioeconomic costs incurred would have reached approximately SEK 2.6 billion. However, it must be noted that the motive for the Stockholm trial was never to achieve traffic-related benefits during the trial period. The main reason for the trial has been to collect experiences, which could support the implementation of permanent measures. If congestion charging were to be permanent, results of the CBA analysis suggest that the investment cost would be repaid in the form of socioeconomic benefits within four years. The benefits are shorter travel times, improved traffic safety and the positive effects on health and the environment. Such result is very favourable compared with investments in road infrastructure, which have a repayment time much longer (15 – 25 years). The expansion of bus services does not seem to be profitable from a cost-benefit perspective, neither during the trial period nor in the event that congestion charging should be made permanent. However, this result is not particularly surprising since many public transport measures are unprofitable in the traditional sense.

5.2 Understanding unsatisfactory outcomes

In Deliverable, 1 a comprehensive framework for policy packaging was outlined which highlighted the importance of key substantive and procedural issues for successful policy packaging. The main components of this framework related to the *ex-ante* optimisation of packages' effectiveness and efficiency, together with *ex-ante* prevention of potential adverse, non-intentional effects. As we have argued in previous chapters, however, despite the comprehensiveness of the policy packaging framework, any policy intervention acting on a complex system will inevitably risk being either ineffective, inefficient or the source of adverse, non-intentional effects. In other words, while they can be minimised, such risks and uncertainties can never be 'designed-out' in their entirety.

In this sub-task, therefore, we are thus assuming that the *ex-post* monitoring procedures have indicated that an initial policy package is somehow unsatisfactory in one or more of these three respects. However, before we can begin to consider implementing remedial actions in order to address this problem, our immediate priority is to *understand why* the package has proved to be unsatisfactory. In terms of effectiveness, we would broadly judge a policy package to be ineffective if it failed to sufficiently influence pre-specified policy target(s) in a desirable fashion. In essence, this can mean one of three things: that the target has not been influenced whatsoever; that the target has been favourably influenced but to an insufficient degree; or that the target has been unfavourably influenced. Second, in terms of efficiency, we would broadly judge a policy package to be inefficient if, in relation to its effectiveness, its direct and/or associated transaction costs are unacceptably high. This can mean that the package has run into major acceptability and/or feasibility problems, or that there are redundant and/or contradictory relationships existing between measures. Finally, in terms of adverse, non-intentional effects, we would broadly judge a policy package to be problematic if it is shown to have had unfavourable impacts on one or more other objectives in either the immediate (primary) policy domain and/or other (secondary domains).[20]

Assuming that the procedural policy packaging framework outlined in Deliverable 1—with its strong emphasis on identifying, explicating and managing causal relationships—has been strictly followed, we can roughly attribute the unsatisfactory nature of a package to a difference between the causal assumptions underpinning the intervention (i.e. expectations) and the actual causal mechanisms that took place in reality (i.e. results). Of course, we should not have overly high expectations of *ex-ante* policy packaging; the initial package only needs to be sufficiently good to move from the development stage to the implementation stage. In other words, analysts should not fall into the trap of attempting to construct a 'perfectly optimal' package in the first instance.

When attempting to understand why a package has proved to be unsatisfactory, analysts may essentially undertake processes of 'error analytics' (Allchin, 2001) or more appropriately what we might term 'limitation diagnostics'. In other words, in order to understand instances of package 'failure', analysts must seek to examine the space in-between their *ex-ante* assumptions and *ex-post* 'reality' in order to determine why a policy package has not performed as expected. In so doing, it is essential to recognise that different forms of limitation are liable to be present. Acknowledging this fact helps to structure efforts to pin-down key limitations in a policy package and also informs the design of subsequent remedial actions designed to ameliorate their harm. Drawing on the conceptual discussion of risk and uncertainty presented in Chapter 2 (see also Kleindorfer, 2008), we can point to two types of limitation that are likely to be of relevance to those seeking to develop *ex-post* explanations of policy failure.

First, we can identify *epistemic limitations*, whereby the *ex-ante* knowledge-base upon which a policy intervention has been developed is somehow inadequate. More specifically, such inadequacy can be understood as resulting from weaknesses in *observational focus* and/or *conceptual reasoning*. Observational focus here pertains to the accuracy of the

[20] In accordance with the typology of non-intentional effects outlined in Deliverable 1, Chapter 3

‘picture’ upon which analysis takes place and relates strongly to the manner in which interventions are perceived and framed. In addition, it also concerns associated methods of data collection and sampling. In contrast, conceptual reasoning pertains to the analytical interpretation and manipulation of the observed ‘picture’ and relates to the use of theoretical or statistical models and their guiding causal assumptions/generalisations.

Second, we can identify *communicative limitations*, where, regardless of the quality of *ex-ante* knowledge, the degree to which such knowledge is shared amongst relevant policy actors is somehow inadequate. This may be characterised by the presence of overly-narrow discourses, lack of sufficient discussion between politicians, analysts, stakeholders and the public, misunderstandings amongst such actors with regard to their respective perceptions, priorities, capacities, or responsibilities, and incompatibilities amongst actors’ tools.

To the best of their ability, therefore, analysts must use all the available real-world *ex-post* monitoring data to try and establish why the patterns present in these data diverge from *ex-ante* predictions. The quality of this process is highly dependent on how detailed the monitoring data are—for only with high-quality monitoring is it possible to establish with any degree of certainty which of the above limitations are most likely to have occurred and are hence responsible for the package being unsatisfactory. Assuming that good monitoring has taken place, analysts ought to be able to home in on the source of error through logical inference. For example, consider the case of a policy package designed to reduce air pollution in an urban area which has failed to reduce the level of the pollution to the desired extent (i.e. it has proved ineffective). Monitoring data may indicate that, in line with causal expectations, car usage (the major source of pollution) significantly decreased during the period of the intervention. Hence, it may be reasoned that the source of the error must lie elsewhere in the causal model.

Combining these insights with the five phases of the OPTIC policy packaging framework outlined in Deliverable 1, **Table 5.1** offers a non-exhaustive sample of some potential limitations that are liable to lead to an unsatisfactory outcome from a policy package. It is worth noting that instances of such limitations are not mutually exclusive; in practice, it is likely that key limitations will be comprised of epistemic (both observational and conceptual) and communicative elements.

Packaging Phase	**Epistemic limitations *(observational focus)***	**Epistemic limitations *(conceptual reasoning)***	**Communicative limitations**
1. Determination of values, objectives and targets	Too naïve a focus/ lack of complexity appreciation	Objective setting without viable targets	Failure to communicate these to 'implementers' downstream;
2. Inventory of measures, provisional measures and causal assumptions	Errors of commission and omission in causal map (variables and/or relationships)	Flaws in causal reasoning (e.g. logical fallacies, confusion of correlation and causation, direction of causality)	
3a. Evaluation: effectiveness and efficiency	Poor conceptualisation of distributional effects (key actors and their interests, beliefs, positions and resources); Unforeseen direct and transaction costs; Failure to accumulate adequate research.	Computational modelling errors (failure to incorporate relevant variables/relationship); inability to identify 'critical paths'; errors of scope'/contextual differences; poor underlying theory (e.g. neoclassical economics vs. behavioural economics); policy transfer problems; inability to accurately predict actors' response to measures (i.e. forecasting limitations); cost overruns due to 'optimism bias' (Tversky and Kahneman, 1974)	Incompatibility between models and MCA/CBA frameworks; over-reliance on output from formal (limited) models; cost overruns due to 'strategic misrepresentation' (c.f. Flyvbjerg *et al*., 2008)
*3b. Evaluation: prevention and mitigation of non-intentional effects (c.f. D1 typology)**	B1Y1 – Blind spot	AZ1 – Overdone; B1Z1 – Off the mark;	AZ2 – Spillover; B1Z2 – Not in my system B2Y – Secondary blind spot
4. Additional measures and inter-measure interaction	Modelling weaknesses (set up); unforeseen interactions (measure to measure; measure to context)	Modelling weaknesses (calibration and parameters); inability to predict synergetic/contradictory relationships; failure to attend to pre-conditional relationships	

* See below for explanation of each of the categories.

Table 5.1 A sample of some potential limitations leading to an unsatisfactory outcome from a policy package.

5.3 Options for remedial action(s)

As noted previously, once analysts have acquired sufficient knowledge of the limitations present in a given policy package, they are in a better position to undertake any remedial actions that may be necessary in order to ensure the package reaches a satisfactory level of performance. In some cases this may involve making relatively small adjustments to one or more existing measures in the policy package, while in more serious cases there may be a need to dramatically redesign the package, through the incorporation of additional measures and/or the complete removal of one or more existing measures. Of course, it may be that the limitations discovered, while unfortunate, are not considered to be overly serious problems with respect to the package's effectiveness, efficiency or its propensity to cause adverse, non-intentional effects. However, in this section we will assume that the given package requires remedial action and seek to examine ways in which this might be approached in a systematic and coherent manner.

A significant proportion of the academic and policy literature on the topic of remedial measures conceptualises the notion in a more generic sense than we do here. This is a common occurrence in the OPTIC project, given that the nature of the research demands fine-grained definitional clarity with respect to key concepts and terminology. The *Oxford English Dictionary* (1989, np.) defines the adjective 'remedial' as 'providing or offering a remedy, tending to relieve or redress something.' For many other authors, the 'something' to be redressed corresponds to the particular problem/ externality which forms the rationale for the policy intervention *per se*. Hence, where these authors use the term 'remedial measure(s)' they are essentially referring to the same approach outlined in OPTIC WP2 (i.e. a policy intervention designed to mitigate some undesirable phenomena that is exogenous to the package). In this chapter, however, our remit is concerned with conceptual 'correcting procedures' whereby undesirable outcomes that result from a policy intervention can be mitigated. For each limitation type, we can point to the obvious forms of practical remedy—respectively, a change in observational methods, a change in concepts, or a change in interpersonal action. We shall now work through the five stages of the policy packaging framework and explore the *ex-post* options for remedial action in the context of the potential limitations of each phase as presented in Table 5.1.

Phase 1. Determination of values, objectives and targets

To reiterate from Deliverable 1, Phase 1 in the policy packaging framework involves three stages: first, the designation of particular phenomena as 'undesirable' in the light of various ethical, moral or utilitarian value systems and world-views; second, agreement upon political objectives made in relation to these phenomena; and third, the identification of specific, measureable targets in order to realise the objective(s). Given the inordinate complexity inherent in each of these stages, decisions made in Phase 1 are likely to be extraordinarily difficult (Ney, 2009). To thus speak of 'limitations' in Phase 1 is perhaps inappropriate, as disagreement is equally, if not more, likely to stem from the presence of different value systems rather than from different views as the appropriate mechanisms for reaching agreed targets or objectives. Nevertheless, Table 5.1 provides examples of three potential oversights liable to occur in this phase, which may be associated with both epistemic and communicative limitations.

First, in relation to observational focus, package sub-optimality may result from the setting of overly simplistic or ambitious objectives that do not reflect the complex nature of contemporary transport problems. A simple example of this might be a policy objective of removing all private motor vehicle traffic from a large urban centre within a relatively short time period. While theoretically possible, such a radical objective would grossly overlook the saliency of associated issues in both primary and secondary policy domains, such as the limited capacity of public transport services or the vulnerability of the local retail economy to fluctuations in consumer patronage. If the failure of a package appears attributable to insular objectives, the remedial action required to remedy the situation may be significant. Indeed, most likely this would involve re-orientating the nature of the policy intervention toward more achievable, realistic or pragmatic objectives. Second, relating to conceptual reasoning, policy objectives may be proposed without the incorporation of relevant, measurable policy targets. For example, actors may declare an overarching objective to be the 'revitalisation of inland waterways', yet fail to specify the criteria upon the extent to which such revitalisation may be judged. In response to evident package failure caused by such a situation, remedial actions ought to involve the explicit articulation of statements about policy intentions and evaluative criteria. Third, somewhat related to this, a form of communicative limitation liable to be present in Phase 1 may be the failure of high-level actors to adequately convey such objectives and targets to 'downstream' policy actors concerned with measure implementation. For example, if policy objectives and targets relating to bike-rail intermodal integration are not adequately communicated to the actors involved in the management of rail stations, genuine policy effectiveness is unlikely to result. The associated remedial actions here would thus involve ensuring that all actors involved in the delivery of policy interventions, however marginal their role, are aware of the intervention's fundamental objectives and targets.

Phase 2. Inventory of measures, provisional measures and causal assumptions

The second phase of the framework is comprised of three stages. First, an inventory of potential primary measures is created. This is intended to be an open and liberal process, with potential measures rarely being rejected outright at this point. The inventory could be comprised of a diverse array of measures, including novel or innovative ideas as well as so-called 'best practices' derived from other spatial/temporal contexts. Second, this inventory is subjected to expert review and one or two primary measure(s) are selected on the basis of key criteria outlined by Banister *et al.* (2000) and discussed in Deliverable 1. Third, the causal assumptions underpinning this selection are codified using a 'causal map'. This final stage is intended to illustrate the direct and indirect processes by which the actors believe the chosen primary measure(s) will influence the various policy target(s).

There are two major epistemic limitations associated with this phase, with each potentially requiring remedial action. First, in relation to observational focus, there may well be certain variables and/or inter-variable relationships present in reality but which are missing from the causal map that forms the rationale for the package design. These 'false negatives' or 'errors of omission' may be relatively insignificant—such as the failure to recognise a minor causal relationship between the level of teleworking in a suburban location and local economic growth—or highly significant—such as the failure to appreciate the feedback mechanism of 'induced demand' when increasing the supply of transport infrastructure. Correspondingly, there may also be variables and/or inter-variable relationships present in the causal map that do not exist in reality. Again, these 'false positives' or 'error of commission' may vary in significance. Second, in relation to conceptual reasoning, the nature of inter-variable relationships may be wrongly estimated, with inaccurate weighting given to key relationship(s) or directions of causality misinterpreted (for example, due to confusion of correlation with causation). For example, on the basis of an unrepresentative sample, analysts may overestimate the extent to which the provision of segregated bicycle lanes may stimulate an increase in cycling.

In relation to both of these epistemic limitations, we can consider remedial action as a two-stage process. First, the causal map underpinning the intervention must be redesigned and/or recalibrated in the light of the information acquired through monitoring activities. This may, for example, require the use of primary research and/or quantitative modelling to more accurately establish causal links between pertinent variables. In undertaking this stage, actors thereby reduce the likelihood of similar limitations in the future and also construct a superior causal model upon which to base the second phase—formulating a suitable policy response to any immediate problems resulting from the flawed map.

Phase 3a. Evaluation: effectiveness and efficiency

Phase 3a of the framework is comprised of two stages, with each drawing heavily on the causal map produced in Phase 2. First, the likely distributional effects of the primary measure(s) are considered and evaluated. The intention here is to determine—insofar as is possible—the likely effectiveness and acceptability of the intervention in its original guise. Next, the knowledge of the intervention's likely effectiveness and acceptability—derived from the causal assumptions and distributional effects—can be appraised against estimates of the intervention's financial viability in order to determine—insofar as is possible—whether the current intervention is likely to represent good value for money.

A number of epistemic and/or communicative limitations may arise in this phase. First, in relation to observational focus, the scope of analysis with regard to an intervention's distributional effects may be inadequate. More specifically, inaccurate estimations may be made concerning the political power of particular stakeholders, the level and nature of opposition to an intervention and/or an intervention's implementation and enacting timescales. For example, public opposition to a proposed high-speed rail link may be far greater than anticipated, incurring transaction costs and potentially requiring project redesign or other forms of remedial action. Also, the causal assumptions underpinning the decision-making in this phase may be based on observed research that is limited in scope. Here, remedial action may be necessary to incorporate relevant research knowledge that is presently unknown or unrecognised. Second, in relation to conceptual reasoning, the conceptual foundations of this evaluation phase may be inherently weak due to a reliance on poor explanatory social scientific theories. For example, an evaluation predicated solely upon the tenets of neoclassical economics, while somewhat helpful, may limit the extent to which analysts can derive a comprehensive, real politic awareness of an intervention's impact. In addition, due to strong institutional circumstances, efforts to transpose particular measures from one location to another may fall short of expectations. Within the EU, this may be particularly evident in attempts to transfer so-called 'best practices' across national boundaries. Where packages appear to have failed as a result of such limitations, remedial action may involve the incorporation of more refined explanatory theories that are sensitive to the behavioural and institutional nuances that characterise contemporary transport systems. On the basis of such action, alterations to the package could be made in order to ensure the intervention is wholly compatible with the socioeconomic context in which it being implemented. Third, in relation to communicative limitations, package failure may stem from an over-reliance on the output of formal modelling tools, whereby such outputs represent the major focus for analytical debate and discussion. Remedial actions here could include triangulation of modelling output with other sources of information to arrive at more refined conclusions (cf. Deliverable 2).

Phase 3b. Evaluation: prevention and mitigation of non-intentional effects

Phase 3b of the framework can also be considered to represent an evaluative stage of the process. Here it is the responsibility of the analyst to conceptualise the intervention in its fullest sense and to take into account the potential risks created by the presence of non-intentional effects in both primary and secondary policy domains. Given the typology of non-intentional effects outlined in Deliverable 1, it makes sense to address their inherent limitations and remedial actions in turn.

B1Z1 – Off the mark

This non-intentional effect is characterised by epistemic limitations pertaining to both observational focus and conceptual reasoning. Here, policy-makers have a relatively correct causal model of a transport intervention (i.e. it includes the relevant major variables), but their weighting of the various elements is partially inaccurate. As with Phases 2 and 3, remedial actions here ought to be concerned with recalibrating the causal assumptions underpinning the intervention—perhaps through primary research and/or quantitative modelling— in order to more accurately establish the character of key causal relationships. The intervention could then be 'tweaked' in order to bring its effects into line with *ex-ante* estimations and policy objectives. For example, this may involve revising the price charged to motorists in a congestion charging scheme.

B1Z2 – Not in my system (NIMS)

This non-intentional effect is characterised by communicative limitations. Policy-makers again have a relatively correct causal model of a transport intervention that includes the relevant major variables, but they omit a part of the whole causal system from their considerations because it does not fall under their jurisdiction. For example, an intervention designed to increase public transport patronage may inadvertently lead to a decline in walking and cycling rates, thereby acting against public health objectives. Here, remedial action ought to involve establishing and maintaining communication links with policy actors in secondary domains so as to minimise the occurrence and damage of such contradictory instances.

B1Y1 – Blind spot

This non-intentional effect is characterised by inadequate observational focus. Here policy-makers assume an inaccurate causal model of the policy situation (i.e. it ignores relevant major variables or interactions), and thus the predicted outcome of the intended effect differ significantly from the actual outcome leading to counter-intentional effects. Remedial actions here are akin to those discussed above in relation to Phase 2—concerned with addressing the presence of 'false negatives' and 'false positives' in actors' causal understandings. For example, if monitoring activities indicate an undesirable growth in car traffic, the causal assumptions underpinning the design of a 'park and ride' scheme may need to be updated in order to incorporate a distinction between urban and rural car travel.

B2Y – Secondary blind spot

This non-intentional effect is characterised by both epistemic and communicative limitations. Here inadequate causal assumptions extend into secondary effects, which may in principle be known before, but are in this case not discovered or considered in the analysis of the policy makers. Following the discussions above, remedial actions could involve redesigning the causal model to take these into account *and* establishing and maintaining communication links with actors in neighbouring policy domains.

B2X – Holy Smoke!

Here, policy-makers' causal models could not possibly incorporate certain variables. An effect occurred that was not known before, never occurred in that policy context or have only existed as speculation. If significant enough, remedial actions could involve complete reorientation of priorities and strategies or the development of contingency plans. A recent example of such a situation was the Icelandic volcanic eruptions in April 2010 and its impact on the aviation sector.

Phase 4. Additional measures and inter-measure interaction

In Phase 4, we are concerned with the manner in which analysts may modify the proposed intervention so as to improve its effectiveness, efficiency and/or limit its propensity to bring about non-intentional effects. A central component of this phase is the systematic analysis of what we have termed 'inter-measure interaction'. This process is concerned with establishing detailed knowledge of potential additional measures' likely relationships and, hence, examining the extent to which such measures may or may not, directly or indirectly, improve the quality of the proposed intervention. There are a number of epistemic limitations that may present themselves in this phase, mostly related to conceptual reasoning. For example, the modelling tools used may be overly simple and incapable of handling the complexity of inter-measure interaction, unable to sufficiently address synergetic/contradictory or pre-conditional relationships. In such instances, remedial actions may be concerned with revising and improving the theoretical and/or practical modelling tools used to appraise the nature of inter-measure interaction (cf. Deliverable 2).

5.4 Conclusions

In this chapter, we have highlighted how one might address policy limitations through *ex-post* monitoring and remedial action. It is somewhat disconcerting that, to date, while significant resources are often directed at *ex-ante* evaluation of policy interventions, little is devoted to official *ex-post* evaluation. Nevertheless, in terms of monitoring, we can distinguish a range of approaches and tools. First, there are straightforward comparisons of pre- and post- intervention indicators which, although simplistic, represent a valuable base upon which to conduct *ex-post* analysis. Second, cost-benefit analyses have been used to assess whether interventions have generated their expected benefits efficiently. Although the quality of CBA outputs can be susceptible to changes in methodology, inputs and short appraisal periods, it nevertheless represents a useful tool for *ex-post* evaluation. This is especially the case where complementary modelling or multi-criteria analysis approaches are used, where non-monetary impacts can be adequately incorporated into the analysis.

In terms of *ex-post* remedial actions, it is important to recognise that this deliverable makes no attempt to offer categorical solutions to situationally-specific 'epistemic' or 'communicative' limitations. Rather as 'meta guidance', its purpose is to offer an overarching framework which can inform analysts who, upon the realisation that a policy intervention is unsatisfactory, are tasked with ensuring that it *becomes* satisfactory. Clearly, such practical remedial actions will remain highly contingent upon the specific problem context. The deliverable hence outlines what ostensibly represents an extension of the *ex-ante* guidance detailed in Deliverable 1, set in the context of the analysis undertaken in Deliverable 2 and the content of previous chapters in this deliverable. A clear implication of the discussion is that monitoring, as in the case of the London Congestion Charge, must be properly planned and adequately funded in order to gain genuine insights into interventions' effectiveness. Failure to ensure that this is an integral part of the policy (package) implementation process will greatly undermine both the feasibility and viability of *ex-post* remedial action, and can therefore undermine the success of the overall policy.

6 Adaptive planning and institutional challenges

To date, there is no common framework for 'adaptive' planning advocated in the literature, nor is it entirely clear what institutional arrangements are necessary in order to cope with adaptation. Although no straightforward framework for action exists, however, reflecting upon selected aspects of an adaptive planning is highly important in the context of this deliverable. Not least, adaptive planning requires entities and decision-makers to be receptive to revising and/or adjusting policies that have been implemented. As already stated in Deliverable 2 (DLR and KIT, 2010, p. 59), conditions for policymaking as well as for institutional settings are unique. Nevertheless, it is recommended in this chapter to consider generic elements of adaptive planning, irrespective of the contingent or 'unique' policy processes. The adjustment of policies should be possible both in the case where only one single measure is implemented, and also if a complex policy package with multiple measures is introduced. In the following sections, we make the case that adaptive planning is a compelling option in the face of policy uncertainty. The following two sections shed light on the core elements of adaptive planning and describe institutional challenges in more detail. Finally, brief conclusions are provided.

6.1 Uncertainty and the need for adaptive planning

As noted in Deliverable 2, although efforts to reduce 'unknowns' can be improved by additional analysis, and policy learning, "unknowns will always be lurking around the corner" (Swanson, 2010, p. 926). Before addressing the role of adaptive planning in this context, it is worth briefly reiterating the interpretation of uncertainty made in this Deliverable. In Chapter 2, two categories of uncertainties were introduced. First, uncertainty was understood in terms of variability, with regard to nature, human behaviour or socio-economic and cultural dynamics. Second, uncertainty was understood in terms of limited knowledge about systems, measurements, conflicting evidence or aspects of ignorance and indeterminacy. These definitions should not be understood as an exclusive description of any type of uncertainty. But they are helpful as they refer to main categories of uncertainty that appear when taking policy action and thus, are of particular relevance in the context of OPTIC.

We concluded that uncertainty and potential unexpected outcomes of a policy, which were not seen during the implementation phase, need to be addressed. To do so, we have already discussed the saliency of remedial actions through *ex-post* measures (see Chapter 5). We also suggested that uncertainties about costs and benefits of a policy should be considered by allowing for flexibility, i.e. opening the possibility for modifications after information becomes available to resolve risks and uncertainties (see Chapters 3 and 4). Given the willingness of some policymakers to fund and apply *ex-post* (and *ex-ante*) assessment methods, we can assume that increased requirements for the respective actors and involved institutions are possible. For instance, extensive assessment requires comprehensive data collection and consensus between different policy actors about new, or at least adjusted policies, have to be found. Despite these additional efforts, it is expected that the continuous observation of policy outcomes enables policymakers and institutions to react to, adapt and adjust policies when or where necessary.

6.2 Aspects of an adaptive planning

The following section focuses on several specific aspects of an adaptive planning given the understanding that "policies have unintended impacts" and that "adaptive policies are designed to function more efficiently in complex, dynamic and uncertain conditions" (Swanson, 2010, p. 924). Although no unambiguous typology of adaptive policy approaches is available, there is a consensus in the literature about its importance. Anticipatory policy should make use of selected indicators to perform monitoring and take into account new information for policy reformulation (Walker *et al*., 2010). In what follows, it is clear that some of the recommendations for adaptive planning have already been addressed elsewhere in OPTIC (e.g. in analysing the relevance of different assessment approaches in Deliverable 2).

In essence, an adaptive planning process prepares for the worst possible development of a policy outcome and tries to assure that a rapid and effective reaction to (unknown) unintended effects is possible. Change and adaptation are integral parts of the planning process. The methods to modify policies that are implemented ought to be formulated precisely and in such a way that the system can be kept heading towards the initial objectives.

(1) One element of an adaptive planning can be *scenario planning techniques*. This refers to participatory methodologies of (e.g. stakeholder involvement) at the outset of policy planning. Adaptation strategies are discussed there against the background of expected future alternative developments.

(2) In accordance with (1), an adaptive strategy could also involve *implementing and testing a variety of policies* when applying assessment approaches. In a multi-stakeholder deliberation, many different actors and opinions broaden the perspective on future developments. This can also be helpful to detect very different unintended effects, even those that go beyond the principal area of interest. The same applies for mainly quantitative approaches. For instance, the simulation of many possible futures (based on assumptions about future development and policies) creates awareness for the range of policy effectiveness and thus shows policymakers which scenarios goals can and cannot be achieved.

(3) Another strategy is the *establishment of 'signposts'* that can help identifying the moment when policy reformulation becomes necessary. This element is part of a monitoring system, using indicators to highlight the need for policy adjustment if values move outside of an intended, desirable range.

(4) In a more *elaborated monitoring system*, the use of indicators is part of a formal, and more important, continuous learning and adaptation process. Checking the quality of the

policy performance is here conducted automatically rather than on an *ad-hoc* basis. Again, the review of policy performance can be based on deliberative action of stakeholders or by the application of quantitative approaches. In so doing, underlying causal relationships of unintended effects that emerge *ex-post* can be identified and be used to improve future decision-making, based on lessons-learned.

(5) Another effective attempt to establish adaptive policy action is to *phase in policies*. This could mean to e.g. first introduce a congestion charging scheme in a smaller area to test the technology or expected behavioural reactions of users. This 'test' would have the advantage that in case of unintended effects showing up, the whole system is not affected at once and corrective action can be conducted.

The elements of an adaptive planning explained in this section should be evaluated against the type of policy that is assessed. For instance, if we revise the five elements of an adaptive planning discussed here, it is obvious that the *testing of various policies* is not feasible when a new cost-intensive infrastructure is built. It is recommended to distinguish at this point between policies that require large investments, such as infrastructure projects, and those of regulatory character, such as a tax or a charging scheme. However, it is possible to address the investment on the infrastructure *ex-ante* and examine its feasibility through the application of quantitative assessment methods. Regarding *ex-post* assessment, the *establishment of signposts* (3), and *monitoring systems* (4), is highly relevant, as they allow for an evaluation of the effective use of the new infrastructure. (1) *scenario planning techniques* are of crucial importance, whether the decision is about infrastructure or a policy of regulatory character. In both cases, it is recommended to apply scenario planning techniques which allow considering different future development paths and stakeholder perspectives. For instance, the impact of different assumptions about future oil prices will have an impact on transport demand in general and thus, on both the expected amount of vehicles travelling on (new) infrastructure as on estimated revenues of a charging scheme. It can be expected that the consideration of different future development paths, creates a notion of how a policy will evolve against a wide array of external developments. In the best case, this knowledge is used to define the most robust policy amongst the available options.

6.3 The institutional challenges

A common notion is that the size of an institution—in our case a political institution with executive power—may condition its flexibility and thus constrain its abilities to adapt (Gifford, 1994). The hypothesis underlying this assumption is that the speed of adaptability to situations that require policy actions, such as the outcome of unknown, unintended effects of a policy, will to some extent depend on the number of responsible entities and authorities involved in the decision-making process. With an increase in the number of involved entities and authorities (vertically within the same institution and/or horizontally between several institutions), the complexity (defined here as institutional challenge to harmonise the decision-making process) increases. Since the integration of different decision-making levels is rather resource-intensive, it becomes more likely that less resources for assessment will be available, or that not all views are taken into account.

Beside the difficulties that come along with institutional structures and responsibilities, a further challenge for adaptability relates to the capability of institutions to develop over time. At the same time as flexibility of institutions is claimed, long-term stability in organisational structures is necessary to guarantee implementation of decisions and monitoring of the impacts that take effect in the long-term. This simultaneous requirement for flexibility and durability of organisations is the institutional framework which has to be considered when discussing mechanisms of adaptability in planning processes. In the context of investment for large-scale, long-term projects, Gifford (1994, p. 112) makes a similar argument regarding two-sided requirements when he states that "if uncertainty is great, the rational policy is to avoid irreversible decisions, maintain flexibility, and collect good intelligence. If uncertainty is modest, the rational policy is to design to achieve long-run economies of scale".

In this sense, adaptive planning becomes a challenge both for the structure in which policymaking takes place (i.e. the institutions involved) and with regard to the efforts necessary to provide a continuous *ex-ante* and *ex-post* assessment of policies. This task is not trivial; as institutions should be flexible and durable at the same time, adaptive policymaking can be awkwardly situated between too much precaution and delayed reactions. It also becomes evident that adaptive planning cannot be achieved without considering additional resources, a further challenge in situations where even the budget for *ex-ante* assessment may be limited. This could be a crucial barrier and most likely favour the introduction of a rather static policymaking framework, without evaluating impacts over time. Unintended effects could be more easily minimised if anticipatory methods and models are used for their detection. But experiences demonstrate that reactive adaptative action still predominates. One reason for this could be the financial aspect, which we mentioned above. When the available budget is small, it might be sufficient—although certainly not ideal—to assess a measure *ex-ante* without assigning funds for *ex-post* monitoring or remedial actions. Policymakers may also interpret the consideration of adaptive strategies even as a threat to them, because it could be interpreted as no confidence to the initial setting of the policy.

We can thus suggest that there are several reasons why adaptive planning is not yet a standard procedure: (a) many administrative levels need to be involved in the setting and potential monitoring of a policy (implying institutional challenges in harmonising decision-making); (b) monitoring and eventual adjustments require continuous resources for planning and analysis and it is often not clear how the need for additional resources are to be met; (d) there is a lack of awareness for the potential benefits or only a low level of willingness to establish the process itself. Institutions tend to be conservative when encouraged to adjust to new processes as this implies a challenge to most well-established planning procedures.

The implementation of adaptive planning strategies and the appearance of an increased demand on institutions are two sides of the same coin. A detailed analysis of the specific demand on institutions given different levels of adaptability is beyond the scope of the OPTIC project. Therefore, we did not aim to address the design of an 'ideal' institutional structure to meet requirements of an adaptive planning, as this would mislead from the objective in OPTIC to provide recommendations that are useful in various policy and institutional settings. But still, we can conclude that the degree to which institutions have to change depends on the extent of adaptive strategies considered. Most probably, some additional tasks (e.g. the collection of traffic counts *ex-ante* and *ex-post*) can be fulfilled by keeping the same institutional structure. Other such as continuous monitoring (e.g. frequently conducted surveys about user satisfaction, mode choice behaviour) can require the establishment of additional entities/units.

Despite this relatively pessimistic scenario due to perceived static institutional structures and the additional efforts and costs, it seems clear that refusing more flexibility in planning and institutional settings would imply less effective policies. The ability to correct policies that produce adverse effects over time would be limited and most probably lead to an inefficient use of resources in the long-term. An example where, despite all the challenges (institutional, resources) adaptive planning faces, elements of it were realised, is the *ex-post* monitoring scheme of the London Congestion Charge: There, a monitoring strategy was formulated that "robustly detect and characterise the main expected effects" or "enable unexpected or unanticipated effects to be determined" (see Chapter 5 in this Deliverable or Transport for London, 2003, pp. 28-29).

6.4 Conclusions

The aspects of adaptive planning discussed above have real legitimacy; they are argued to improve policy outcomes by reducing number and/or magnitude of unintended effects. But still, the question must be asked to what extent they are applicable given the specific circumstances of institutional jurisdictions, interests of policy makers or the extent of available financial and other resources. These issues could not be addressed entirely in this chapter, but it is important to recognise them, especially as they might hinder the implementation of the elements introduced above. We identified the following critical aspects regarding these challenges: (a) if sufficient resources (personnel and budgetary) are foreseen by institutions for the operation of monitoring systems and for a regular updating of analytical assessment of policies; (b) if continuation of (institutional) convictions and responsibilities can be assured with regard to the initial policy goal; an issue that most probably is uncertain if the policymakers experience regular, periodic changes in political governance; (c) if the monitoring and the review of an implemented policy is under the responsibility of the same institutions that had introduced it. The latter is especially important because the 'outsourcing' of the monitoring can reduce the risk that of political or personal bias letting the policy deviate from its original target.

To summarise, adaptive planning is about the consideration of assessment approaches *ex-ante* and *ex-post*, continuous learning and evaluation of policy impacts and appropriate modifications in policy design over time. It embraces signpost-based monitoring and requires acknowledgement of the risks and uncertainties associated with setup of a policy (package). In this context, the idea of adaptive planning sets the overall conceptual background for aspects addressed throughout the OPTIC project. The elements of an adaptive planning introduced in this chapter—despite the associated challenges that were discussed—are promising with regard to improving policy outcomes. One or several of the mechanisms presented can ensure that initially set policy goals are still achieved in a complex and dynamic environment where changes of policy impacts over time are expected. Nevertheless, more examples of 'good practices', where aspects of adaptive planning are considered, are useful. This should become a matter of future research.

7 Conclusions and worked example

Policymakers in the transport sector are often required to make decisions in the face of risk and uncertainty. Most evidently, this stems from a lack of information concerning a particular transport problems, the inability of existing modelling tools to accurately encompass the range of variables and causal relationships involved and the messy, intractable nature of the policy process itself. Risks and uncertainties are particularly pertinent to the context of policy making at an EU level, where an extraordinarily diverse array of technologies, markets and political, institutional and socioeconomic contexts are present. As we have reiterated throughout this deliverable, contemporary European transport systems may thus be considered to represent complex socio-technical systems, prone to conditions of path-dependency and lock-in effects.

While OPTIC Deliverable 2 focuses on the ability of a variety of quantitative and qualitative methods and modelling approaches in addressing unintended effects, this deliverable has focused upon how concepts of risk and uncertainty might be integrated into planning process, *ex-ante* and *ex-post*. Chapter 2 offered a conceptualisation of risks and uncertainties, recommending that these be approached in accordance with a typology framed around ‘knowns’, ‘known unknowns’ and ‘unknown unknowns’. Although this chapter further emphasised that unintended effects can never be fully excluded from planning processes in transport policy, it stressed that there are a range of causes of unintended effects that can, in theory, be removed. Chapter 2 also re-visited unintended effects, first described in OPTIC Deliverable 1, focussing on their core characteristics and emphasising the importance of actors’ situational knowledge.

Chapter 3 focused on the notion of irreversibility, the interactions of irreversibility and uncertainty. In this chapter two interpretations of irreversibility that are relevant for the mitigation of unintended effects were adopted. The first interpretation related to instances where a return to the status quo is impossible or extremely difficult, at least on a relevant timescale, and corresponds most closely to the arguments of environmentalists. The second interpretation sees irreversibility in terms of sunk cost, corresponding to the definition in economic literature on options theory. In this chapter, the argument was made that irreversibility is only of concern if there is a significant degree of uncertainty present in a situation. Over long-term horizons, unpredictable technological change, changes in land use, population shifts, changes in values and preferences, etc., make the uncertainties over policy’s costs and benefits great. Discount rates are also inherently uncertain, and a long time horizon makes that uncertainty especially important. Hence the assumption of stability of the parameters in the traditional transport demand models is contested. The notions of path dependency and lock-in are also addressed in this chapter. Following economic theory, it was argued that instances of path-dependency may often be explained through the concept of increasing returns and briefly reviewed some important sources of increasing returns in the transport domain. It is pointed out that traditional models in economics are not appropriate for the prediction of the outcome and it is not easy to change from a lock-in by standard tax or subsidy policies prescribed by economists for a change to a more socially desirable situation. Exit from an inferior lock-in situation depends very much on sources of the self- reinforcing mechanism. It is emphasised that the recognition of path dependency and lock-in effect are important for many transport policies.

Chapter 4 addressed the importance of irreversibility and its policy implications and briefly described methodologies available for the integration of risk and uncertainty in the design of policy interventions. Specifically, three key policy areas in the EU and national transport sectors, where uncertainties and irreversibility are substantial, were briefly reviewed: alternative fuels and vehicles; infrastructure investments; and environmental problems. The purpose of these reviews was to illustrate the inadequacies of the traditional quantitative models for the evaluation of policy formulation in each of these areas (cf. Deliverable 2; DLR and KIT, 2010). A further purpose of the review is to emphasise the need for flexibility in planning when uncertainties and irreversibility are present.

Drawing on elements from Chapter 2, Chapter 5 discussed how analysts might address policy limitations through *ex-post* monitoring and remedial action. In terms of monitoring, several main approaches and tools were distinguished, arranged according to a continuum of suitability for *ex-post* packaging and subsequent remedial action. In terms of *ex-post* remedial actions, it is important to acknowledge that this chapter was not designed to offer a complete answer to every 'epistemic' or 'communicative' limitation that might arise. Rather as 'meta guidance', its purpose is to offer an overarching framework which can inform analysts who, upon the realisation that a policy intervention is unsatisfactory, are tasked with ensuring that it *becomes* satisfactory. Clearly, such practical remedial actions will remain highly contingent upon the specific problem context. The chapter hence outlined what ostensibly represents an *ex-post* extension of the *ex-ante* guidance detailed in Deliverable 1, set in the context of the analysis undertaken in Deliverable 2.

Finally, Chapter 6 focussed on the challenges of flexibility in planning and the institutional challenges that this poses. Accepting that uncertainty and irreversibility and the propensity for unintended effects are endemic to contemporary transport problems, it is recommended that policy makers follow an 'adaptive planning' approach when formulating, implementing and evaluating policy interventions. Traditional approaches to decision making that assume a deterministic model of the world in which the future is predictable were argued to be limited in usefulness. Instead, a number of adaptive techniques such as: scenario planning, policy testing and the establishment of 'signposts" were put forward as more suitable approaches.

Overall, this deliverable advocates a comprehensive, challenging and resource-intensive policy-making process with a strong emphasis placed upon various *ex-ante* and *ex-post* activities, such as causal mapping, modelling, packaging and monitoring. Clearly, the current economic climate might not favour this approach, regardless of its theoretical strength. As a result, it is perhaps advantageous to reiterate the core consideration that emerges from this deliverable: the importance of adaptive and flexible policy-making.

Indeed, without such flexibility, *ex-post* activities such as monitoring or remedial action simply become worthless and obsolete, respectively. As noted, coping with complexities plays a crucial role in planning process; the more complex a system, the greater its associated uncertainties, and thus the greater need for flexibility to be embedded in the design of policy measures. Flexibility is thus both important in the context of policy intervention irreversibility (e.g. investment in heavy infrastructure) or irreversibility associated with the problem that the policy package itself aims to mitigate (e.g. anthropogenic climate change). Fortunately, as stressed in Chapter 3, situations of great uncertainty may simultaneously be situations with where a degree of leeway is present, enabling actors to consider the nature and deployment of a range of potential measures.

With the body of relevant knowledge gathered and built upon in Work Package 3, described in this deliverable and in Deliverable 2, Work Package 4 now proceeds to examine a series of 'best practice' examples of *ex-post* and *ex-ante* policy packaging approaches within the EU. Drawing upon the conceptions of risk, uncertainty, monitoring and remedial actions outlined here, this will serve to highlight the pragmatic, context-dependent concerns of European policy-makers and thereby provide a fuller picture of the nature of policy packaging and its relation to policy effectiveness. In addition, Work Package 6 later draws on this deliverable in order to provide recommendations on optimal policy packages and factors influencing their transferability across national and regional boundaries.

Worked example: transport infrastructure provision

In concluding this deliverable, it appears worthwhile to synthesise the message of the preceding chapters by way of a short, hypothetical example. Consider, for instance, the following fictional scenario. In conjunction with the European Commission, three adjoining new member states, with major city-regions A, B, C and D, respectively, are considering various policy options to improve the accessibility and efficiency of key transport corridors. The present situation is far from ideal; congestion on the existing, poorly-maintained road network is significant and set to increase in the future. Following the policy packaging framework set out in Deliverable 1, the analysts involved have proposed a simple policy package designed to meet this accessibility objective.[21] The package consists of two synergetic measures: (1) the provision of new cross-border, motorway infrastructure linking the three cities and (2) a corresponding system of road pricing designed to raise revenue to finance the infrastructure provision.

Given the content of the preceding chapters, we can begin to explore issues of risk, uncertainty, monitoring, remedial action and adaptive planning in the context of this example. In particular, we can approach this in terms of two key decision-making stages: *ex-ante*; and implementation/*ex-post*.

[21] For the purposes of argument, we keep this example simple and refer only to this one objective. Clearly, in practice, there will be several social, economic and environmental objectives involved in such an endeavour.

Ex-ante considerations

In addition to the *ex-ante* considerations of effectiveness and efficiency inherent in the policy packaging framework set out in Deliverable 1, this deliverable has stressed the need to address issues of risk and uncertainty well in advance of policy implementation (cf. Chapters 2, 3 and 4). In the context of this hypothetical example, we can clearly appreciate why such issues are of importance. While small infrastructure projects can be designed and constructed within relatively short timeframes, it takes much longer time to successfully implement such large-scale project, especially where it involves multiple political jurisdictions (cf. Section 4.3 for further characteristics of large infrastructure projects). Hence, there are considerable risks and uncertainties associated with such projects, both related to supply-side issues (e.g. cost overruns) and demand-side (e.g. the development of demand over time in different parts of the network) and discount rate (see Section 3.3.1). For example, in this context there may be uncertainties associated with technological developments (e.g. emergence of alternative fuels/vehicles, intelligent transport systems, new forms of smart freight distribution), the development of fossil fuel price and true social carbon emissions costs.economic changes (e.g. prolonged recession, industrial restructuring), political/ideological changes (e.g. diplomatic tensions) or socio-behavioral changes (e.g. consumption patterns, leisure patterns)

Attending to such risks and uncertainties *ex-ante* in a comprehensive fashion would involve analysts engaging with the 'removable causes of risk and uncertainty' outlined in Chapter 2. In this case, this might include: guarding against overt 'rent-seeking' behavior by certain actors or organisations; ensuring that the causal assumptions underpinning the infrastructure provision and charging scheme are as comprehensive and conceptually-sound as possible, while ensuring that powerful actors or stakeholders are prevented from unjustly changing these assumptions to better align with their interests; striving to ensure that long-term costs and benefits (especially those related to the infrastructure provision) are adequately incorporated into the appraisal process, resisting the short-term imperatives of certain actors; ensuring that a viable balance is reached between the complexity of the *ex-ante* causal models underpinning the intervention and their usability/interpretability; and ensuring that the agency of the policy-making process itself does not adversely affect the scheme outcome.

Nevertheless some risks and uncertainties can't be resolved ex-ante (such as those associated with the economic growth and fuel prices). By applying real options theory it is possible to develop a stochastic model for the net present value (NPV) of road infrastructures. The results might show that a delay option (or a reduced option such as a lower than full capacity) may be an important source of value in the CBA framework, even if the expected NPV of starting right away is positive. As emphasised in chapter 5 the real options approach amounts to a framework for improving investment decisions in the presence of uncertainty and irreversibility. Compared to traditional investment approach such as NPV, this perspective takes into account the value to react flexibly to situational changes and integrates the impact of varying uncertainty levels and sources on investment decisions. In this sense the real options provides a methodology to assess the opportunities and benefits associated to flexible investments. The McDonald and Siegel (1986) seminal paper provides the basis for the analyses of the optimal timing of investments. The examples of the application of real options to infrastructure decision timing in literature are Rose (1998), Zhao *et al.* (2004) and Godinho and Dias (2010).

Implementation/ex-post considerations

Insofar as scheme implementation and *ex-post* considerations are concerned, there are a number of issues raised in this deliverable that are important to note. Following the arguments put forth in Chapter 6, we can broadly approach such issues through the lens of 'adaptive' planning, whereby continuous evaluation of policy impacts support analytical learning and facilitate appropriate modifications to policy design over time. In the context of this hypothetical example, this approach could first manifest itself in the *phased introduction* of one or both of the measures in the package. For example, it may be possible to introduce the infrastructure provision in stages by acquiring the right-of-way for the entire project, but constructing a two lane motorway (instead of the full capacity of a four or six lane motorway). Using comprehensive, signpost-based *ex-post* monitoring, analysts could thus 'take stock' of the intervention's impact (in terms of its effectiveness, efficiency and production of unintended effects) before deciding whether to continue with the original plan, or to introduce targeted remedial action.

The same principle is applicable to the road pricing scheme. Policymakers may opt to first introduce pricing on certain links in the network or at certain periods of peak traffic flow. Once again, signpost-based monitoring allows for the knowledge learned from of such 'trials' to be re-incorporated into the design of the intervention itself to ensure that the operation of the scheme enables key revenue targets to be met. For example, if *ex-ante* estimates of long-term fuel prices were significantly underestimated, and thus demand for the new scheme falls short of the levels anticipated, the financing of the scheme may be jeopardised. Adaptive planning, grounded upon detailed *ex-post* monitoring and analysis, can act as a support mechanism in such a situation—aiding the effectiveness of analysts' and policy-makers' decision-making procedures in their quest to design a remedial solution involving, for instance: fee increases, charging cordon extension or infrastructure plan revision.

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