Environmental Valuation, Ecosystem Services and Aquatic Species

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"Let neither measurement without theory
Nor theory without measurement dominate
Your mind but rather contemplate
A two-way interaction between the two
Which will your thought process stimulate
To attain syntheses beyond rational expectation"

Arnold Zellner (Journal of Statistical Planning and Inference, 1996)

Abstract

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The thesis consists of an introduction and four articles that can be read independently of each other. The common topic is environmental valuation and cost-benefit analysis. The applications relates to the growing concern of invasive species, and to waterpower externalities. In broad terms, all of the articles relates to water management.

Article 1: "A Cost-Benefit analysis of introducing a non-native species: the case of signal crayfish in Sweden", assesses the economic impact of introducing the signal crayfish into a Swedish lake. Two scenarios are set up and compared. The first one assumes that there is no introduction of signal crayfish, so that the noble crayfish is preserved. In the second scenario, the signal crayfish is introduced, which immediately wipes out the entire stock of noble crayfish. The values of noble- and signal crayfish populations are measured as present values of their net future revenues. The values are than compared and net benefit of an introduction is calculated. The result indicate that net benefit of an introduction is positive if the intrinsic growth rate or the carrying capacity of the noble crayfish is below 40 % that of the signal crayfish.

Article 2: "Assessing management options for weed control with demanders and non-demanders in a choice experiment", estimates the benefits of having a weed management program for a lake in Sweden, and then compares them with corresponding costs. The policy recommendation from a simple cost-benefit rule is to control the weed at some specific sites of the lake. This paper also suggest how to distinguish those that have a positive WTP for at least one of the attributes (demanders) from those that have zero WTP for all attributes (non-demanders). The advantage of the suggested approach is that it facilitates to more clearly distinguish between conditional and unconditional willingness to pay. The suggested approach could also overcome some of the problems in the literature with negative welfare measures.

Article 3: "Assessing transfer errors in the benefit transfer method: An application of invasive weed management using choice experiments", tests the accuracy of transferring benefits of a weed management program from one lake to another using choice experiment. The transfer errors are assessed and the convergent validity hypothesis is tested. Estimating the accuracy of benefit transfer for weed management is policy relevant as there are a number of lakes in Sweden infested with the water weed. The convergent validity was rejected for three out of five welfare estimates with a ten per cent significance level.

Article 4: "Willingness to pay for environmental improvements in hydropower regulated rivers", assesses the benefits of environmental improvements along hydropower regulated rivers using choice experiments. Remedial measures that improve the conditions for fish, benthic invertebrates and river-margin vegetation were found to have a significant welfare increasing impact. The results can be of value for the implementation of the Water Framework Directives in Sweden, which aims to reform the use of all surface water and ground water in the member states.

Keywords: bioeconomics, invasive species, non-market valuation, choice experiments, benefit transfer, water management.

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Preface

In order to complete this thesis I have gained a lot of encouragement and help from different people. I would like to take this opportunity to show my gratitude to some of them. First of all I would like to thank Fredrik Carlsson. I got to know Fredrik as I attended a PhD-course for him. Ever since then, Fredrik has guided, helped and encouraged me in my research. I will always be indebted to Fredrik for constantly encouraging me and taking his time to discuss econometrics with me. He also inspired me with his open attitude to share knowledge with other people. I guess Fredrik will always remain my teacher (I certainly want to keep being his student), however, with time Fredrik has also become a true friend.

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Uppsala, January 2007
Mitesh Kataria

Contents

Appendix

The thesis is based on the following articles, which are referred to by their Roman numerals.

I. Kataria, M. A Cost-Benefit Analysis of Introducing a Non-Native Species: the case of signal crayfish in Sweden. *Marine Resource Economics,* Volume 22, pp. 15-28.

II. Carlsson, F and Kataria, M. Assessing Management Options for Weed Control with Demanders and Non-Demanders in a Choice Experiment. *Submitted to Land Economics (Revised and resubmitted, 2nd round)*.

III. Kataria, M. Assessing Transfer Errors in the Benefit Transfer Method: An Application of Invasive Weed Management using Choice Experiments. *In submission to Environmental and Resource Economics.*

IV. Kataria, M. Willingness to Pay for Environmental Improvements in Hydropower Regulated Rivers. *Submitted to Journal of Energy Economics.*

1 Introduction

The overall theme of this thesis is environmental valuation and cost-benefit analysis. The aim is to by the means of new estimates consistently organize obtained information and thereby contribute to the policy analysis. The applications relates to the growing concern of invasive species, and to waterpower externalities. Invasive species and their control have public good aspects in the sense that the benefits of control are neither rival nor exclusive. This could call for some level of government intervention. However, there are very few empirical studies that have throughout assessed the economic impact of invasive species. In order to understand the scope of the problem and develop appropriate management response, empirical and theoretical research in this area is deemed to be necessary. Water power externalities are assessed in relation to the Water Directive Framework which strives to reform the use of surface and ground water in member countries. In common, all of the articles relates to water management. Together with the policy related research, some attempts have also been made to contribute to the methodological development in the non-market valuation literature. Namely, a modified approach in choice experiment is suggested, and the validity of the benefit transfer method is tested.

The thesis is organized as follows. This section starts with some preliminary remarks about cost-benefit analysis. In section 2 the empirical models of the articles will be put in a broader theoretical context. Different methods of valuing non-market and environmental goods are discussed in section 3. Special weight is put to review the contingent valuation- and choice experiment literature and discuss some empirical properties. The aim of the first three sections is to give the reader a comprehensive understanding of environmental valuation before proceeding with the articles. Hence, in the first three sections the method of the articles is discussed. Section 4 broadens the understanding for some of the applications (in article 1, 2, and 3) by putting them in a context which relates to invasive species. Section 5 summarizes the papers in the thesis and section 6 concludes the thesis with a discussion. I will keep the first sections less formal and proceed in an (intuitive) non-mathematical fashion. The target group is readers with limited knowledge in environmental valuation. Some statistical knowledge could ease the reading in section 3. The rest of the thesis consists of four separate articles. These articles are found in the appendices of the thesis.

1.1 Cost-Benefit Analysis

A recurrent question in managing environmental resources is to what extent a society should invest in costly measures to improve or maintain certain environmental quality. Economists have the tradition to approach this type of questions using normative decision theories where cost-benefit analysis is given a central role. More accurate, economic efficiency defined by the Pareto or potential Pareto criteria is given a central role. The Pareto criteria states that a policy change that makes at least one person better off without making anyone worse off is Pareto improving and should be undertaken. In practice there are very few, if any, policy changes that make no one worse off. The potential Pareto criterion can be seen as a further development of this concept. In a simplistic form it states that if

the winners of a policy change can compensated the loser's and still be better off, the policy change should be undertaken, (Hicks (1939); and Kaldor (1939)). Given that the compensation is actually paid (using taxes and transfer payments) no one will actually experience a welfare loss. Hence under these circumstances the Pareto and potential Pareto criteria are intrinsically related.

An interesting question is whether Pareto efficiency should be assessed independently from other concerns such as the distributional question. As noted earlier, in practice there are very few policy changes that make no one worse off and in order to achieve Pareto efficiency, winners of the policy must compensate the losers. However, the tools that politicians can use to redistribute income from winners to losers can in turn have disturbing effects on efficiency. This could be an argument to approach these questions simultaneously. Focusing on the potential Pareto criteria and leaving the distributional question to others is an approach economist's often seem to have preferred. This standpoint is often justified with reference to utilitarianism which regards an action justifiable as long as it yields a greater net value for the society. Utilitarianism was originally proposed by Jeremy Bentham and further developed by John Stuart Mill. Utilitarianism allows for skewed (non-symmetric) distribution of winners and losers of a policy even if the efficiency incremental policy implies more losers relative to the winners.

Another attempt to justify the one-sided focus on efficiency, without falling back to utilitarianism, would argue that a large number of efficient projects will spread the total benefits randomly over the population, or at least sufficiently wide over the population. Polinsky (1972) formalized this thought by broadening the notion of a single proposed policy change to include bundle of changes having some randomness in distribution. The probability of actually being made worse off is then showed to approach zero as this multiple-change approach with increasing number of efficient projects is considered.

Taking a step back, let us turn from discussing if it is justifiable to take an action that yields net value for the society, to consider if preferences should be accounted in decision making at all. Hence, a cost-benefit analysis implicitly accepts and accounts for subjective preferences in decision making. However, can preference satisfaction and economic efficiency be justified as a policy goal? Some argue that preferences are in fact unobservable and even if we could observe preferences, preference satisfaction cannot be justified as a policy goal (Sagoff, 1994). Proceeding with arguments in this line, Sagoff (2004, p.181) continues "Rather, the goals of society, for example, clean air and water, the protection of species, and the maintenance of wild and scenic areas, are intelligible to those without (but perhaps not those with) advanced degrees in policy analysis. The question society must answer is how and where it can pursue these goals most efficiently, that is, at the lowest political and economic cost". An interesting question is what distinguishes Sagoff's "choice of goals" from what economist's call preferences, and what makes these "choices of goal" superior and incomparable to preferences in general? That is, besides the mere stipulation that they are superior and incomparable goals of the society in distinction to preferences. In contrast, others argue that individuals preferences are revealed by individual choices and that they

should indeed count. The latter standpoint does not rule out that there are other trade-offs which undeniably have to be considered. We will not enter deeper into this discussion. However, interested readers are referred to Mitchell and Carson (1989) who to some deeper extent discuss alternative decision criteria's to economic efficiency and preference satisfaction. Among other criteria, they mention paternalism and egalitarianism as incompatible alternatives to a cost-benefit analysis. A thorough discussion about the tradeoff between equality and efficiency can also be found in Okun (1975) and Baumol (1985). We end this discussion by simply concluding that utilitarianism, paternalism as well as egalitarianism are all based on normative assumptions and can be criticized as well as justified on ethical grounds. Nevertheless, even if economic efficiency is not the only goal of the policy-maker, a cost-benefit analysis can still be of interest in order to assess how much of efficiency that has to be sacrificed to achieve other goals. Assessing these trade-offs certainly does not require a utilitarian basis. Sorting out the trade-offs could, however, greatly improve the outcome of the policy analysis. Nevertheless, a cost-benefit analysis should neither be viewed as sufficient or necessary for designing a sensible public policy (Arrow et al. 1996).

2 Theoretical framework

The environmental valuation literature is directly related to consumer and demand theory in economics. In this section some fundamental concepts will be discussed, mainly to guide readers who are not familiar with this literature. The aim is to put the empirical models of the articles in a broader theoretical context.

Basic theory of individual preferences and the demand for goods starts with assuming consumer sovereignty, meaning that the consumer knows what gives her utility. Moreover, if the consumer prefers a certain bundle A over a bundle B, then bundle A is assumed to be the utility maximizing choice between these two choices. In other words, given well-defined preferences the consumer is assumed to, when facing fixed prices and budget restriction, chose the quantities of the goods such that her utility is maximized. The obtained relationship between price and quantity demanded is known as the Marshallian demand function in economics. The area under the Marshallian demand function bounded by the horizontal price line is known as the ordinary consumer surplus. The welfare change of the consumer resulting from a change in either consumption or from a change in prices and the budget is known to be captured by the change in the consumer surplus (Marshall 1920). The consumer surplus measure, however, is not consistent with the underlying utility function.

Consistent consumer welfare measures defined in terms of the underlying utility function was first introduced by Hicks (1943). In contrast to the Marshallian demand function, the Hicksian demand function is the solution of the expenditure minimization problem given fixed prices and a constant level of utility instead of income. For a price change the change in consumer welfare is known as compensating- or equivalent variation, depending on whether the utility level before or after the policy change is fixed as the reference case. For a quality change of a good, the corresponding measure is known as compensating- or equivalent surplus. More specifically, the compensating surplus will be the

maximum amount of money the individual will be willing to abstain from in order to secure a qualitative improvement. The equivalent surplus will be the minimum amount of money the individual will be willing to accept to forgo the quality improvement. For quality deterioration the compensating surplus will be the minimum amount of money the individual will require to accept this change. The equivalent surplus will be the maximum amount of money the individual will be willing to abstain from in order to avoid the quality deterioration. In short, whether we consider quality improvement or deterioration, the compensating surplus takes the initial utility as the reference point while the equivalence surplus takes the utility after the change as the reference point.

To summarize, basically there are three different measures reflecting the consumer's welfare for quality changes. Using the Marshallian demand we have the ordinary consumer surplus measure. Using the Hicksian demand we have the compensating and the equivalent surplus measures. Besides for some special cases these measures will not coincide. Willig (1976) calculated the difference between consumer surplus, compensating variation measure and equivalent variation measure. The difference appeared to be rather small for most realistic cases. This means that the ordinary consumer surplus could be used to approximate the Hicksian welfare measures i.e. compensating and equivalent variation. Bockstael and McConnell (1993) showed that Willig's analysis for the price change could, however, not be generalized when it came to the compensating and equivalent surplus measures. Their result is important in relation to valuation methods where the welfare of policy changes is measured using the observable Marshallian demand function.

3 Valuation methods

Methods to measure the effect on the consumer's welfare for non-market goods given a policy change are divided into direct and indirect methods. Direct methods elicit stated preferences and makes use of stated preference data. Indirect methods make use of real market behaviour and revealed preference data. We will in this section briefly distinguish these two different approaches from each other by discussing how they are linked with the welfare theory. The focus of the rest of the overview will then be on reviewing the direct methods. This is consistent with the articles of the thesis which mainly deals with stated preference data.

3.1 Indirect methods

Production function-, travel cost- and hedonic price methods are all well-known in the valuation literature and belong to the group of indirect methods. Using data from actual market behaviour is considered to be a great strength in favour for these indirect methods. A popular strategy considering the indirect methods is to treat and describe the public good as a quality characteristic of a privately consumed good. However, there are some limitations and shortcomings of the indirect methods which deserve to be mentioned. One of the shortcomings is that it limits the researcher to only assess welfare changes that are reflected in the market. Mäler (1974) showed that in order to trace the welfare effect from a change in the public good, certain restrictions has to be imposed on the underlying

utility functions. These restrictions involve what Mäler called weak complementarity. Weak complementarity requires the marginal utility of the public good to be zero when the quantity demanded of the complementary private good is zero. The interested readers are referred to Mäler (1974) for a thorough exposition. The weak complementary restriction rules out existence value and other non-use values which may be essential to include in a policy assessment. Also remember that that the ordinary consumer surplus could not in general be justified as an approximate to the Hicksian compensating and equivalent surplus measures. We will now turn to the direct methods of non-market valuation.

3.2 Direct methods

Contingent valuation (CV) and Choice experiments (CE) are two frequently applied non-market valuation methods belonging to the group of direct methods. Using the direct methods, the economic value of a good is assessed through survey questions that elicit the individuals' preferences. In doing so, the theoretical correct welfare measures (Hicksian) is obtained. Needless to say, these are not the only empirical methods that use data from surveys. Other examples where economists use survey data are, for example, census surveys and consumer expenditure surveys. The use of surveys, however, has been a controversial topic among economist. McCloskey (1985) noted that a mere suggestion to send out survey's can get an audience of economists to laugh out loud. Much of the debate in the valuation literature has been about whether respondent's truthfully reveals preferences in hypothetical surveys or if there is a "hypothetical bias". There is of course not a simple answer to this question. Undoubtedly, there are inherent problems with direct methods. This does not imply, however, that all surveys have biased estimates. Mixed results from external validity tests indicate that neither does all survey's suffer of hypothetical bias, nor can the problem be ignored. Researchers has for the past years invested a lot of research of how to reduce the hypothetical bias.

Nevertheless, in contrast to indirect methods, direct methods include non-use values when assessing the total value of a good. A review of the contingent valuation and choice experiment method will follow in the two coming sub-sections.

3.2.1 Contingent valuation

The idea of the CV method was first suggested by Ciracy-Wantrup (1947). The first applications were presented by Robert K. Davis (1963a, 1963b, 1964). In the early applications the respondent was simply asked about their maximum willingness to pay for a change in the supply of an environmental good. This type of questions is known as open-ended questions in the CV literature. Bishop and Heberlein (1979) introduced the dichotomous choice question, where the respondent is given a valuation question which can be either accepted or rejected. The dichotomous choice question has been dominating the CV literature for a time now. Hanemann (1984) suggested a way to integrate the dichotomous choice question with economic theory using the random utility framework. He also suggested how compensating and equivalent surplus could be measured from

these models. The random utility framework had previous to Hanemann been introduced by McFadden in a series of papers and books, see, for example McFadden (1973).

The random utility model is typically estimated as the difference of a linear utility function and additive systematic error, using Logit or Probit models. These models assume the stochastic part to be unbounded from minus to plus infinity. Since the errors are unbounded, the willingness to pay function will also be unbounded. However, in many applications researchers wants to restrict the willingness to pay to be strictly positive and negative welfare measures is considered as unrealistic. In contrast to the random utility framework, Cameron (1988) introduced an approach that directly focuses on the willingness to pay (WTP) distribution rather than the stochastic part of the utility function. The advantage of this approach is that it could restrict the willingness to pay to be strictly positive and lead to more plausible distributions. For example, Cameron used an exponential willingness to pay function, which overcomes the problem with negative willingness to pay estimates. However, the mean WTP for this model is an increasing function of the variance, which seems to make it vulnerable for what is known as fat tails (Haab and McConnell 1997). For a thorough discussion about different ways to bound the willingness to pay function, see Haab and McConnell (1998).

The overall conclusion seems to be that eliminating the possibility of negative willingness to pay also increases the sensitivity of the parametric models to distributional assumptions. Kriström (1990) suggested a non-parametric approach where the distribution function assumption is not critical. Several other researchers suggested variants of distribution-free estimators around this time. A related development in the parametric contingent valuation literature was the introduction of the spike model by Kriström (1997). The spike model distinguishes zero willingness-to-pay respondents using likelihood function where these respondents are given a separate probability specification at zero WTP. The spike model can overcome the problem of negative willingness to pay, although it is theoretically not a direct means of handling negative willingness to pay if it still allows a symmetric distribution from plus to minus infinity.

3.2.2 Choice experiments

The CE technique combines the characteristics theory of value by Lancaster (1966) with the random utility theory. In contrast to the CV method where the individual's utility is derived directly from a good, the Lanchester approach (and CE) assumes that individuals derive utility from the characteristics of the goods. This facilitates a multidimensional valuation of several attributes of a good as well as a total value of the good.

CE has developed from stated preference techniques evolved in marketing as well as transport economics. Some of the earliest transportation applications using discrete choice models are from the 1960s, and aimed to estimate the trade-off between travel time and travel cost using travel demand models. Research during the early 1970s was oriented toward mode choice models with more than two

alternatives (see Ben-Akviva and Lerman 1985, for an overview). Around the same time, conjoint analysis was coined by Green and Rao (1971) in the marketing literature. Conjoint analysis includes any technique used to estimate attribute utilities based on individuals responses to combinations of different attributes. Hence, in a conjoint task, respondents rank or rate a set of profiles (combination of attribute levels) on, for example, a scale of desirability. Based on observed rating or ranking, the researcher could statistically deduce the relative importance of the attributes and attribute levels for the respondents. Louviere and Woodworth (1983) introduced CE, also known as choice-based conjoint in the marketing literature. In a CE the respondent is asked to select his or her most preferred alternative among several alternatives. The alternatives consist of different combinations of attribute levels, and each set of alternatives is known as a choice set. For a comprehensive overview of choice experiments, see Louviere, Hensher and Swait (2000) and Alpizar, Carlsson and Martinsson (2003).

Whether the respondent is asked to rank, rate or select his or her most preferred alternative, the researcher has to find a way to compose the different profiles or choice sets. This is usually achieved using experimental design theory. Important tradeoffs are usually made when designing a CE study. On the one hand, the researcher wants for administrative and budget reasons, to keep the experimental design with as few survey versions or blocks as possible. However, such designs come to the cost of additional assumptions about interaction effects between attributes in the design. The simplest design, a main effect design, assumes that there are no interaction effects.

The choice design literature has gained a lot from the concepts and results of the linear design literature. Traditionally, the emphasis has been on model identification instead of statistical efficiency, i.e. precision of parameter estimates. Orthogonal designs where the levels of each attribute vary independently have been preferred. One merit of the orthogonal design is that the parameter estimates of a linear model will be uncorrelated. However, lately, the focus seems to have changed towards statistical efficiency.

For linear models, the variance of the parameters is proportional to the information matrix. Hence, for a linear model the covariance matrix is obtained as the product of the information matrix and the homoscedastic variance of the residual (sigma squared). This means that a design with a "smaller" covariance matrix will provide more precise parameter estimates, hence higher efficiency. A common measure of the size of the covariance matrix and the design efficiency is D-efficiency (Zwerina 1997). Extending results from the linear design theory to choice design could however be misleading. Zwerina (1997) showed that in contrast to the linear model, the efficiency of the design for the conditional logit model does not only depend on the combination of attribute levels in the design, but also on how the alternatives are combined in the choice set. As in the case for linear models, an intuitive understanding of how to construct efficient designs can be gained by just looking at the covariance matrix of the conditional logit model. The covariance matrix of the conditional logit model will be a function of the parameters of the model. In order to obtain an optimal design the researcher therefore benefits from

knowing the parameters of the model. This is of course controversial, since if we already knew the parameters there would be no need for a CE study. Without any prior information a conventional first step in choice designs is to assume all parameters to be equal to zero or at least use some priors like signs for the attributes. To use the estimated parameters from pilot-studies could be another way to go in order to achieve design efficiency. A third and crude approach is to use some a priori expectations of the parameters and achieve utility balance by eliminating too dominate alternatives in the choice set, see Wiley (1978) for details. Carlsson and Martinsson (2003) have, using Monte Carlo simulations showed that D-optimal designs with prior information produce unbiased parameters with lower mean squared errors than orthogonal designs. Moreover, their results were not very sensitive when the choice sets were generated using D-optimal designs with biased priors.

We now turn to the econometric analysis of CE studies. Whereas rating and ranking data could be handled by the use of conventional statististical methods such as ordinary least squares (OLS), choice experiments have, because of the discrete dependent variable, traditionally been estimated using probabilistic choice models such as logit, probit and conditional logit. The conditional logit has two important restrictions: (i) independence of irrelevant alternatives (IIA), and (ii) homogenous preferences. The IIA axiom states that the ratio of the probabilities of choosing one alternative over another is unaffected by the change of other alternatives in the choice set. In some instance the IIA property can give rise to erroneous predictions. The second restriction is that conditional logit model excludes the possibility that respondents can have heterogeneity in taste. Alternative econometric models are often applied to overcome these problems, such as nested logit models (Ben-Akviva 1973; Train et al. 1987; Lee 1999) and heteroskedastic logit models (Bhat 1995; Hensher 1997). Another model gaining increased popularity is the random parameter model. In the random parameter model the parameters of the model vary over individuals in the population with a certain density. The random parameter model is estimated using simulation techniques since a closed form solution doesn't exist for the log-likelihood function. A neat feature of the random parameter model is that it facilitates individual parameter estimates, using Bayes' rule, see Train (2003) for details.

The first study to apply CE to non-market valuation was Adamowicz et.al (1998). Since then there has been an increasingly number of CE-studies for non-market valuation, especially in health and environmental economics. Although Adamowicz acknowledge several advantages using CE over CV, as the possibility to examine the value of several attributes, some concerns were also raised. In particular the negative welfare measures associated with movement away from the status quo alternative was troublesome. The problem with unrealistic negative welfare measures (unrealistic in most applications) was familiar from the contingent valuation literature. Recently there has been some progress in these matters in the CE literature. Haffen, Matthew and Adamowicz (2005) used different hurdle models to distinguish serial nonparticipants from other respondents. Carlsson and Kataria (2005) set out a spike model where demanders

are distinguished from non-demanders. These models can to some extent overcome the problem with unrealistic negative welfare measures.

4. Invasive species – definitions and analysis of concepts

Three out of four papers in this thesis deal directly or indirectly with invasive species. A definition of invasive species is therefore in place. Invasive species are species whose introduction cause or are likely to cause economic or environmental harm or harm to human health, (U.S. executive order 13112)[1]. This definition leaves a need for clarification as it is vague. Environmental harm will henceforth be interpreted as a change in the environmental equilibrium caused by some introduced species and where the population of animals or plants are affected negatively. In contrast, economic harm will henceforth be interpreted as a negative effect on human welfare caused by some introduced species. Harm on human health will be captured implicitly by the definition of economic harm. Hence, environmental- and economic harm are both independent sufficient conditions for introduced species to be defined as invasive species. Moreover, by introduced we mean that the species are moved by humans outside their native range. It can be deliberated as well as unintentional. In distinction to invasive, non-indigenous species are species that are moved by humans outside their native range but neither do cause harm to animals, plants nor human welfare. These distinctions are presented in figure 1.

	Harmful	**Not Harmful**
Introduced	Invasive	Non-indigenous
Not Introduced	Native	Native

Figure 1: Defining invasive species

This thesis analyzes the economic effects of two invasive species, namely the signal crayfish and the yellow floating heart. The signal crayfish is considered as invasive species as it eradicates the population of the noble crayfish. The yellow floating heart (water weed) is considered as invasive as it has a negative impact on human welfare. However, note that identifying the species as invasive doesn't always change the economic analysis per se. The management problem can still remain the same whether the species is invasive or not. For an example, the

[1] For a description of the Executive Order see http://www.invasivespecies.gov/laws/main.shtml.

economic analysis whether or not to control a waterweed looks the same irrespectively if it is invasive or native. This example aims to show that the categorization as invasive species only adds a conceptual dimension to the understanding for the applications in this thesis, not an analytical. In contrast, if the aim would have been to analyse measures to prevent introduction of invasive species the analysis could have differed as an introduction per se is a unique feature of invasive species. Moreover, an understanding of invasive species introduction involves an understanding of the means and routes which species are introduced into new environments, i.e. pathways. The risk of establishment of invasive species from ships' ballast water serves as an example where invasive species management adds a conceptual as well as analytical dimension to the policy analysis.

Finally, also note that invasive species could be economic desirable as well as undesirable. However, as the reporting of invasive species in general is done for those introduced species which are economic undesirable, the understanding of invasive species is likely to be associated with economic undesirable species. Whether this can be explained by ontological reasons meaning that most invasive are economic undesirable, or epistemological reasons, is a different subject. Invasive species that neither are economic desirable or undesirable will probably get the least attention. This does definitely not suggest that the actual problems with invasive species are negligible. Pimentel et al (2005) reported that invasive species in the United States cause major damages and losses adding up to almost $120 billion per year. Invasive species cause a global economic problem and policies that prevent further damages as well reduce the impact of current damages need to be looked into.

4.1 Invasive species management

In this section the articles of the thesis will be put in a context which is comparable with respect to the growing literature of invasive species management. Note that the aim is to put the applications in the thesis in a meaningful context, not to review the invasive species management literature.

This literature distinguishes at least two kinds of management practices, namely control and prevention. Control[2] involves actions that reduce the impact of invasion without changing the likelihood that it will occur or spread further to other and new parts. In contrast, prevention involves actions that reduce the likelihood of invasions or spread of invasive species. This thesis deals with control as well as prevention. Control relates to the water weed application and prevention to the crayfish application. However, the crayfish application evaluates different scenarios where one scenario is assumed to entirely eliminate the risk that the invasive crayfish gets introduced, while another scenario allows the introduction. This case differs from prevention in a more traditional sense where prevention is likely to reduce the risk of invasion, but not completely eliminate this risk. The merit of these extreme scenarios in the crayfish application lies in quantifying the

[2] Control can involve eradicating, suppressing or reducing invasive species populations.

effects of a policy that prevents introduction. Posed in a different way, the analysis provides monetary estimates on the net benefits of an introduction, which could be suggestive whether a further spread should be prevented or not. We will come back to the crayfish application in section 5.

Let us use the case of the invasive waterweed to further exemplify some of the intriguing decisions which has to be made considering invasive species management. Before the invasive waterweed becomes established, the policy-maker has to decide upon to what extent to invest in measures that prevent and reduce the probability that invasion occurs. Based on normative decision theory, this requires knowledge about the invasive species in several dimensions such as the likelihood of invasion, the conditional likelihood of invasion on invasion-preventing actions, and the cost and benefits of actions that reduce the likelihood of invasion. In short, the effect of an invasion as well as probability of an invasion has to be known ex-ante an invasion.

Once an invasion has occurred, the policy-maker has to decide upon to what extent to control the waterweed and reduce the impacts of invasion. Evaluating control measures involves addressing questions like whether or not to control the weed, as well as where to control the weed given its occurrence. Normative decision theory would suggest assessing the cost and benefits of adopting a weed management program.

Finally, a decision has to be made considering if it is warranted to take actions to prevent further spread of the weed in the infested lake as well as to other lakes. To be able to evaluate actions that prevent further spread of the weed, knowledge of conditional and unconditional likelihood of the weed to become infested on actions that reduce this likelihood is desirable, and in addition the cost and benefits of the weed management program is also needed. Note that analysis of control of the invasive species can find support in traditional decision theory. In contrast, prevention involves theories for decision under risk and uncertainty; more interested readers are referred to the work of Neumann and Morgenstern (1944), Savage (1954), Arrow (1951) and Debreu (1959).

Perrings (2005) reports disparate beliefs among researchers whether or not invasions and effects of invasions are predictable or not. This reminds of Knight's (1921) famous distinction between "risk" and "uncertainty". Knight referred "risk" to situations where mathematical probabilities can be assigned to the randomness of an event, whereas "uncertainty" is situations when this randomness cannot be expressed in terms of specific mathematical probabilities. This distinction is disputed and many economists mean that uncertainty is a problem of knowledge of the relevant probabilities, not of their existence. Either case, when invasions cannot be expressed with mathematical probabilities, whatever the reason is, evaluating actions to prevent an invasion can become problematic.

4.2 Theory with measurements

Having made a rigorous literature review, Lovell and Stone (2005) arrived at the conclusion that there only are a few theoretical, and even fewer empirical studies, dealing with the economic costs of aquatic invasive species. Moreover, only a small fraction of these seem to exist in formal economics literature. Those studies that are available primarily concentrate on theoretical considerations with relatively little empirical analysis. The total number of bioeconomic models included in their literature review was five. The amount of studies that had estimated the benefits of control seems according to their review, be even less. Only one paper in the review made use of the random utility model. This could reflect that very few papers are available.

The purpose of this section is in very broad terms to reflect about the literature considering invasive species management. Hence, although it seems to be acknowledged by Lovell and Stone (2005), among others, that there only exist a few studies dealing with economic cost of aquatic invasive species, I would like to address the question if and how more estimates can contribute to the literature.

To begin with, let's have a very short reflection about the methodological approach of the theoretical contributions in this field. To start with, assumptions about invasive species as well as the behaviour of economic agents can be set up. From the assumptions together with the objective function of the agents, optimal response of the economic agents can be deduced in a traditional neoclassical way. The good thing about deductive logic is that it is truth-preserving, meaning that if the assumptions are true the conclusions of a deductively valid argument will also be true[3]. The limitation is that the conclusion cannot say more than what already is implicit in the assumptions. Hence, the argument does not expand our knowledge in the sense that the conclusion does not reveal anything besides what has already been implicitly stated in the assumptions. However, complicated relationship can be made more explicit using deductive logic. Nevertheless, the optimal response of the economic agents in a deductive model will be a function of various set of parameters. Meaning that the model can help to understand the problem in hand, however, if the purpose is to set up efficient policy, the model has to be correct and the parameters of the model has to be known. Using this reasoning, it is easy to see that parameter estimates are necessary to be able to say something meaningful about the policy of invasive species management.

The applications in this thesis deal with specific case studies where policy questions in relation to invasive species management are addressed. The estimates obtained indicate the scope of the problem being studied and the analysis suggest appropriate management responses. More estimates and empirical work together

[3] However, what if the assumptions are known to be false? Friedman (1953) published a provoking book in which he denies the relevance of truthful assumptions in economic theory. He argues that only the predictive quality of a theory matters.

with analysis can contribute to knowledge about how to set up efficient policy in relation to different management problems with invasive species.

5 Summary of the articles

The objective of this section is to summarise and bring out the main contributions of this thesis. The thesis consists of four separate papers, which all aim to analyze economic valuation using empirical methods for policy and decision purposes.

5.1 Article 1: A Cost-Benefit analysis of introducing a non-native species: the case of signal crayfish in Sweden

The signal and noble crayfish are freshwater invertebrates which are considered important for the Swedish food culture. Sweden has the highest per capita consumption of crayfish in Europe and large quantities of the crayfish are imported every year. The signal crayfish was introduced in Sweden 1960 as the crayfish plague had devastated many of the noble crayfish populations (Hamrin 1993). However, years of observations indicate that the signal crayfish has competitive advantages and crowd out noble crayfish if they occur in the same surroundings. Observations are partly driven by the fact that many of the introduced species have been carrier of the plague during the years. The signal crayfish can act as a host for the plague, but seems not to become infected unless exposed to extreme stress. However, because of competitive advantages the signal crayfish seems to drive out the noble crayfish even in plague-free surroundings (Westman, Savolainen and Julkunen 2002).

An introduction of the signal crayfish is these days forbidden where it does not already exist and where introduction of the noble crayfish is feasible (Järvi and Thorell 1999). Regulation aims to preserve the threatened population of noble crayfish. The aim of this article is to assess if regulations to prevent signal crayfish introduction are beneficial. The noble- as well as the signal crayfish competes for the same habitat and both of them have a commercial value. A conventional bioeconomic model is used and the values of the noble- and signal crayfish populations are measured as present values of their net future revenues. The values are than compared and net benefit of an introduction is calculated. The result indicate that net benefit of an introduction is positive if the intrinsic growth rate or the carrying capacity of the noble crayfish is below 40 % that of the signal crayfish.

This was among the first attempts to estimate the economic impact of species introduction using a bioeconomic model. In that sense, this paper did some novel attempts. However, the analysis of the paper is limited in several ways. The simple bioeconomic model used in this paper uses limited information as a first approximate to provide guidance. The main merit of the paper is that it attempts to apply a framework to consistently organize information about species introduction. The main restrictions come from the poor data and for that reason the result should be interpreted with some caution. Shortcomings of the simple bioeconomic model are discussed in length in the paper. We will only discuss

some of the main shortcomings and suggest how to extend the analysis of the paper to cover a broader policy interest.

Assessing the net benefit of an introduction aims to ex-post evaluate a policy that forbids introduction of the signal crayfish at all Swedish lakes. Hence, introducing the signal crayfish comes to the cost of the noble crayfish and vice versa. However, result of the paper is only able to indicate if introduction is beneficial or not conditional on differences on population growth between the two species. Hence, the paper estimated the population growth for one of the species, while growth for the other is simulated. This restriction is caused by the lack of availability of data where both of the species coexist for a longer period. Another limitation of the paper is that it solely focuses on values reflected on the market prices of the species. Non-use values such as existence values could have been neglected. Both use-values and non-use values should be included in a complete analysis. However, if only existence value is at stake, the question is if current policy that forbids introduction of the signal crayfish is not too strict? Is it not enough to preserve the noble crayfish in some lakes? Addressing these questions involves assessment of conditional and unconditional probability that noble crayfish becomes extinct in one watercourse given that the signal crayfish is introduced in an additional watercourse. More precisely, the probability of a total extinction of the noble crayfish would be desirable. Clearly, although this paper provides some necessary estimates and analysis, more interesting work is to be expected in some of the directions pointed out.

5.2 Article 2: Assessing management options for weed control with demanders and non-demanders in a choice experiment

The yellow floating heart is a water weed causing nuisance problems in Swedish watercourses, which interfere with boat traffic as well as recreation activities such as fishing, swimming and canoeing (Josefsson and Andersson 2001). The purpose of this article is to assess the benefits of having a weed management program and then compare them with corresponding costs. A weed management program can be designed in different ways, not the least when it comes to where in the water system one should control the waterweed. In order to guide the policy-maker on how a weed management program should be designed, the benefits of a weed management program are estimated and a choice experiment study is conducted. The policy recommendation from a simple cost-benefit rule is to control the weed at some specific sites of the lake.

This paper also develops a method to distinguish those that have a positive WTP for at least one of the attributes (demanders) from those who have zero WTP for all attributes (non-demanders). This facilitates a clear distinction between unconditional and conditional WTP; the conditional being the WTP for demanders. Hence, the suggested approach provides the policy-maker with additional information to understand how important the public good is to different groups of people. Facilitating a probability mass (spike) at zero WTP can also overcome some of the problems in the literature with negative welfare measures. In order to distinguish demanders from non-demanders the econometric model as

well as the design of the survey differs from what is conventionally used in the literature.

The problem with unrealistic (unrealistic in most cases at least) negative welfare measures has gained recurrent attention in the valuation literature. In the contingent valuation literature the problem has been approached differently by different researchers. Cameron (1988) introduced an approach that directly focused on the WTP distribution rather than the stochastic part of the utility function. The advantage of this approach is that it could restrict the willingness to pay function to be positive and lead to more plausible distributions. The disadvantage is that it becomes vulnerable for what is known as fat tails (Haab and McConnell 1997). Kriström (1997) introduced the spike model in contingent valuation. Yet another approach which overcomes the problem of negative welfare measures is variants of the non-parametric models.

The problem in choice experiments is similar to the problem in contingent valuation. Adamowicz (1998) reflected about troublesome negative welfare measures in the very first choice experiment in environmental economics. The model presented in this paper can overcome some of the problems in the literature with negative welfare measures.

5.3 Article 3: Assessing transfer errors in the benefit transfer method: An application of invasive weed management using choice experiment

Contingent valuations as well as choice experiments are methods which are costly to apply. Still, an overview of the contents of the two primary journals in resource economics, *Land economics* and the *Journal of Environmental Economics and Management*, revealed that approximately one-third of the published papers between 1990 and 1992 were engaged in valuation (Vatn and Bromley 1994). Clearly, a large number of resource economists are engaged in empirical valuation work. The purpose of all this work is often to provide the policy-maker with information and gain a more efficient use of resources. However, a fair question is if it's really necessary to conduct a new and costly valuation study for each new policy decision. Posed in a different way, is it not possible to make a better use of existing valuation studies instead of conducting new valuation for each new policy decision? Hence, is it not possible to interpolate from estimates which already exist?

Using benefits from a "study site" to a "policy site" is known as benefit transfer in the resource economics literature. As time and money are limited resources, this method is gaining increasing popularity among policy-makers. The question mark, however, concerns the validity of this increasingly popular method. There is at present a bulk of evidence on the accuracy of benefit transfers where the benefits are estimated using the contingent valuation method (see, for example Kirchoff, Colby and LaFrance 1997; Barton 2002). However, there are only a few studies that have used the benefits from choice experiments and assessed the accuracy of transferring the benefits from study- to policy site (see, for example Morrison *et al*. 2002; Bueren and Bennet 2004; Hanley, Wright and Alvarez-Farizo 2006;

Hanley et al. 2006). Results from these studies are mixed. To be able to draw some general conclusions about the possibility to use choice experiment in benefit transfer, more evidence is clearly required.

The purpose of this article is to put the benefit-transfer approach to a test using choice experiment. Using estimates from choice experiments in benefit transfer gives some advantages compared to contingent valuation. Hence, a choice experiment gives a unique possibility to exclude non-interesting attributes from the study site when transferring the welfare measures to the policy site. This means that additional to differences in socioeconomic characteristics, choice experiment facilitates different changes in site quality when transferring benefit estimates.

The benefit transfer test is applied for an invasive weed management program, namely the yellow floating heart. Nuisance problems of the aquatic plant have been reported and the weed is said to interfere with boat traffic as well as recreation activities such as fishing, swimming and canoeing, (Josefsson and Andersson 2001). There are currently about 40 sites in Sweden where the weed is known to be infested (Larson and Willén 2006). Estimating the accuracy of benefit transfer is deemed to be policy relevant because of the number of lakes in Sweden infested with the water weed. The convergent validity hypothesis (implying that two welfare measures are statistically equivalent) is rejected for three out of five welfare estimates with a ten per cent significant level. Transfer errors range between 9 and 79 per cent for all beside one of the welfare estimates. As for future research it could be of interest to include some additional lakes in the analysis to identify what essentially drives the error in transferring the benefits between the lakes. For example, is the transfer error lower when transferring the benefit between similar sized lakes than lakes that substantially differ in size? Or is it perhaps the amount of substitutes which solely drives the error term? These types of questions are left to future research.

5.4 Article 4: Willingness to pay for environmental improvements in hydropower regulated rivers

The European Water Framework Directive (2000/60/EG) strives to reform the use of all surface water and ground water in all member states to attain a "good ecological status" by the year of 2015. How exactly to interpret ecological status is at present not determined, but a classification of "good ecological status" will be based upon biological, hydrological as well as chemical factors in the final judgment. For those waters which will not pass the criteria of good ecological status, remedial strategies could be of consideration. However, an economic analysis of water use in the member countries is required by the Water Framework Directive. The aim of the economic analysis is to assess whether the costs to achieve the improvements are reasonable. One way to approach this question is to assess the benefits of the improvements and compare them with the costs of achieving them. This article focuses on rivers in Sweden which are regulated to obtain hydroelectricity. Regulation to obtain hydroelectricity can considerably change landscape structure and lead to impoverishment of natural diversity

(Nilsson 1996). There are around 1900 hydroelectric power stations in Sweden, whereof 700 are considered to be large scaled since they have an effect above 1.5 Megawatt. Furthermore, about 50 percent of the electricity produced in Sweden comes from hydroelectric power stations (Hovsenius 2002). During the past years, the knowledge of ecological effects of hydropower generation as well as the possibilities to remediate these waters has increased substantially (Nilsson 1996). However, data necessary for complementary economic analysis is still insufficient.

Using a choice experiment study, Swedish households' willingness to pay for electricity with reduced amount of impact on the environment is assessed. Some of the policy relevant questions are; how do the households perceive the different environmental attributes obtained by applying remedial measures? Are some of the attributes preferred over others? Furthermore, how high is the household's willingness to pay for these environmental attributes?

All together, this study provided some understanding of how Swedish households in average perceive environmental attributes which can be obtained by remediation of the hydropower regulated rivers. Clear evidence was obtained that Swedish households have a willingness to pay for environmental improvements in hydropower regulated waters. The obtained input from this article can be viewed as a part of a more comprehensive work in relation to the Water framework Directive in Sweden.

6 Discussion

The contribution of this thesis goes in two separate directions. A central theme of the thesis has been to analyze economic valuation using empirical methods for policy and decision purposes. The thesis contributes with relevant estimates and analysis in relation to water and natural resource management. The applications partly relates to the growing concern of invasive species, but also to waterpower externalities and the attempt of the Water Directive Framework to reform the use of waters in member countries. In short, all of the articles relates to water management. The estimates and analysis can be used to identify how to more efficiently manage our resources.

For the application with the signal crayfish, results suggest that only if there are significant biological differences between the two competing species, economic gains can be realized by allowing an introduction of the signal crayfish. For the water weed application the policy recommendation from a simple cost-benefit rule is to control the weed at some specific sites of the lake. Finally, turning to the hydropower study, results suggest that there is a willingness to pay for many of the environmental improving measures.

The thesis also attempts to contribute to the methodological development in the non-market valuation literature. Distinguishing demanders and non-demanders in choice experiment is one such attempt. The suggested approach can overcome some of the problems in the literature with unrealistic negative welfare measures.

Testing the validity of benefit transfer approach is another attempt to contribute to the methodological development. Hence, only a limited amount of studies, previous this study, have used benefits from choice experiment to test for convergent validity. The results from these studies have been mixed, and more evidence is deemed to be required. Transfer error ranged between 9 and 79 per cent for all beside one of the welfare estimates in our particular case.

As three out of four articles in the thesis relate to invasive species, a fair question is whether or not something general can be said considering invasive species management as a neat synthesize of these articles? However, the author has neither intended to make any general points about invasive species management, nor believes that something interesting has come out in this respect. The thesis mainly contributes to this field of the literature by showing what can be learnt by experience and data considering specific case studies related to invasive species. Rigorous case studies using thorough assessments and empirical estimates of the impacts of invasive species are relatively rare in the literature. When available, they can provide valuable and useful knowledge to the policy-maker for the specific case to understand the scope of the problem and develop appropriate management responses.

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