Environmental Compensation is not for the Birds

Assessing social welfare impacts of resource-based environmental compensation

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Cover: An adult sea eagle (*Haliaeetus albicilla*) found under Turbine #61 on April 16, 2008. A total of 32 sea eagles have been found under turbines at the Smøla wind farm in Norway between 2005 and April 2010.
(photo: Espen Lie Dahl, Norwegian Institute for Nature Research)

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Abstract

The European Union (EU) recently implemented the Environmental Liability Directive (ELD), requiring that environmental damage be restored so that the affected environment returns to (or toward) its baseline condition and the public is compensated for the initial damage and the losses during the time it takes for the environment to recover (interim losses). Equivalency Analysis (EA) represents a method for scaling environmental compensation to offset interim losses. Ensuring appropriate compensation for resource loss requires a merging of ecological measurement with the theories of welfare economics. This thesis explores some of the issues in scaling resource-based compensation in three papers. Paper I is a quantitative application of the EA method to compensate for sea eagle mortality from wind turbine collisions. It is co-authored with a biologist and proposes a new and innovative compensatory measure based on electrocution prevention on power lines. Paper II is written for an ecological readership and communicates fundamental economic assumptions in a way that might be helpful for cross-discipline collaboration. The main contribution is to clarify that the underlying goal of environmental compensation should be "no net loss of welfare." Paper III scrutinizes the conventional EA method from a social efficiency perspective, suggesting that the focus on equity for the victim may preclude a socially optimal compensatory outcome. The overarching conclusion is that EA fails to inform policy makers of the inescapable environmental trade-offs that arise in compensating environmental losses.

Keywords: Equivalency Analysis, environmental compensation, welfare economics, environmental liability, Cost-Benefit Analysis

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Dedication

I dedicate this thesis to Emma Wichardt, who helped support through several years of research.

The coincidence of prefixes in the two subjects is thoroughly appropriate. The Greek root means household and it signifies an interacting set of individual activities, both complementary and competitive with each other. The predator benefits from the growth in both numbers

and individual size of the prey, yet one cannot say the relation is entirely beneficial to the latter. One nation may gain from the growth in other nations from increased exports to them but also lose as they compete for scarce resources such as oil.

— Kenneth Arrow (2007) Nobel prize winner in economics in a guest editorial entitled "Eco(nomics/logy)" in the journal "Ecological Research"

"... let us go beyond mere salvage to begin the restoration of natural environments, in order to enlarge wild populations and stanch the hemorrhaging of biological wealth. There can be no purpose more enspiriting than to begin the age of restoration, reweaving the wondrous diversity of life that still surrounds us."

— E.O. Wilson (1992) The Diversity of Life

Contents

List of Publications

This thesis is supported in part by work contained in the following papers, referred to by Roman numerals in the text:

I Cole, Scott and Espen Lie Dahl (2012). "Scaling electrocution prevention measures to compensate for white-tailed eagle (WTE) mortality losses at the Smøla wind-power plant, Norway." *(Submission to interdisciplinary journal planned May 2012*)

II Cole, Scott (2011). Wind power compensation is not for the birds: An opinion from an environmental economist. *Journal of Restoration Ecology*. Volume 19, Number 2. March.

III Cole, Scott (2012). Equity over efficiency: a problem of credibility in scaling resource-based compensation? (*Submission to economic journal planned May 2012*)

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Abbreviations

BYs	Bird Years
CBA	Cost-benefit analysis
CERCLA	Comprehensive Environmental Response, Compensation and Liability Act (US)
CV	Compensating Variation
DBYs	Discounted Bird Years
EA	Equivalency Analysis
EIA	Environmental Impact Assessment
ELD	Environmental Liability Directive
EU	European Union
HEA	Habitat Equivalency Analysis
HH	Household
NINA	Norway Institute for Nature Research
OPA	Oil Pollution Act (US)
PPP	Polluter pays policy
REA	Resource Equivalency Analysis
REMEDE	Resource Equivalency Methods for Assessing Environmental Damage in the EU (www.envliability.eu)
SWF	Social welfare function
VEA	Value Equivalency Analysis
VPP	Victim pays policy
WTA	Willingness to accept
WTP	Willingness to pay

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1 Introduction

There is an increasing demand for governments to measure and assess the human welfare impacts of ecological change. Specifically, there is a demand to improve methods that quantify the effects of ecological change in ways that facilitate the valuation of that change by economists, for final use by policy-makers. Such methods are commonly used in environmental Cost-Benefit Analysis (CBA) where, for example, policy-makers may want to evaluate the potential net benefits to society of a new road, bridge, wind farm development or other infrastructure project. But such methods are equally important -- and in equally high demand -- for assessing the magnitude of environmental damage for the purpose of scaling appropriate amounts of environmental compensation (ten Kate 2004; McKenney 2005; Englen 2008).

Environmental compensation refers to the provision of environmental resources to offset environmental damage. In contrast to financial compensation, where the compensation mechanism is a cash payment, the focus here is on the use of environmental resources provided through a restoration or preservation project. For example, the unintended release of oil into a wetland may lead to the provision of environmental compensation in the form of either (a) improving the on-site post-spill level of environmental services through habitat restoration; (b) purchasing and protecting a nearby wetland threatened by development; or (c) re-constructing a wetland (on- or off-site) that provides similar services to the one damaged by the spill. Another example may focus on lost recreational use (e.g., reduced fishing days) following a chemical spill at a popular sport fishing lake. Compensation in this case may involve improving the fishery (on- or off-site) or improving public access at alternative fishing sites. A third example is provided in Paper I, where a project to reduce sea eagle electrocution at nearby power lines is suggested to compensate for eagle mortality from wind turbine collisions.[1]

Environmental compensation requirements are on the rise globally, though are not entirely new.[2] In addition to the long-established Natural Resource Damage Assessment regulations in the US[3], the European Union (EU) implemented the Environmental Liability Directive (ELD, EC/35/2004), requiring that environmental damage be remediated (restored) so that the affected environment returns to (or toward) its baseline condition and the public is compensated for the initial damage and the losses during the time it takes for the environment to recover (interim losses). Some international treaties also address compensation (Mason, 2003). In other cases, compensation may be required before undertaking development projects (*ex ante* compensation). There are also examples of environmental compensation to facilitate permit approval, so-called "permitted injuries" in exchange for environmental improvements on- or off-site (Allen et al 2005; Peacock 2007). Finally, governments are increasingly concerned about the rate of global biodiversity decline (ten Kate, 2004; McKenney 2005). Biodiversity offsets represent a compensation mechanism aimed at addressing society's ecological loss (Ozdemiroglu et al 2009).

A compensatory assessment (or "damage assessment") is inevitably an interdisciplinary challenge: economists cannot assess the impact of environmental damage on an individual's well-being without first trying to explain the expected decline in ecosystem services, usually with reference to a baseline condition or other ecological factors that are meaningful to human welfare assessment (see "ecological endpoints" Boyd 2006). That is, economists must rely on the language of ecology to explain the attributes and expected outcomes of proposed compensatory projects. Table 1 identifies some of the relevant

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1 For a Swedish example of ex ante environmental compensation, see the Botniabana railroad project (Banverket 2006). Rundcrantz (2006) summarizes compensation within Swedish road construction.

2 One commenter notes that issues of 'in-kind' compensation has arisen in the case of hydropower development in Sweden as early as the 1950s, though it is experiencing a resurgence of sorts in recent years.

3 The NRDA regulations apply under the 1980 Comprehensive Environmental Response, Compensation, and Liability Act, CERCLA (see 42 U.S.C. 9607(f)) and the 1990 Oil Pollution Act, OPA (see 33 U.S.C. Sec. 2706(d)(1)).

questions addressed by the different disciplines in an environmental compensation assessment.

Table 1 Interdisciplinary contributions to a compensatory assessment

Economics
• identify a means of measuring human well-being • convey scientific information to the public & policy-makers in a meaningful way • measure individuals' willingness to substitute lost for gained resources • highlight distributional impacts of compensation on society ('winners & losers') • develop scaling methods to meet deterrent and compensatory goals
Ecology
• quantify change using "ecological endpoints" that are conducive to valuation • identify and motivate the selection of compensatory restoration projects • monitor and report on the success of restoration projects over time
Law (both international and national)
• assesses the type and scope of activities that face compensation requirements • interpret guidelines for restoration scaling methods (e.g., Annex II of the ELD)
Ethical
• debate human intervention in ecological systems (Hilderbrand et al 2005)

While there are a number of synonyms for environmental compensation[4] -- each of which may have different legal meanings -- this study assumes one distinguishing characteristic: that the beneficiary is society itself. Compensation is an anthropocentric concept aimed at society's well-being or, more specifically, the well-being of individuals within society, including the well-being of future generations (see Paper I). This is consistent with the generally accepted social norm that if an individual is harmed, that harm can be compensated by providing the individual with something in lieu of his/her first choice.

Another way of expressing this is to say that environmental damage per se does not have meaning in a world devoid of human existence, just as 'sustainability' would not exist as a concept without mankind.[5]

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[4] e.g., compensatory/complementary remediation or restoration, biodiversity offsets, environmental restoration, rehabilitation or replacement, compensation ratios, no net loss, net gain, compensatory mitigation, compensatory measures, environmental liability, etc

[5] Some argue that ecological integrity should be maintained 'for its own sake,' but this is, in itself, a reflection of individual (or societal) preferences.

The implication is that our compensatory scaling methods will reflect this human-centric view. The scaling methods assessed in this study assume that the primary goal is *no net loss of social welfare*, although in some cases a simplifying assumption is made that welfare impacts move proportionately with impacts to ecological metrics (Paper II). But this assumption is restrictive as it fails to account for, among other things, nonlinear effects of ecological change on welfare such as tipping points.

The focus on human welfare losses rather than pure ecological losses need not preclude ecological (or even ethical) motivations for compensation, as society's welfare depends critically on ecosystem services such as biodiversity, nutrient and carbon cycling, water purification, flood control, provision of recreation, etc (TEEB 2010). Further, one may posit that mankind shoulders an ethical responsibility to protect species and their habitat (see footnote previous page). However, the focus on human welfare will, in most cases[6], address these ancillary issues because restoration projects that compensate for human welfare losses inevitably benefit ecological resources, while also demonstrating an ethical responsibility.

This study's point of departure for analyzing compensatory scaling is the Equivalency Analysis (EA) method. It has been the predominant method in the US since the mid-1990s and is likely to increase due to the requirements of several EU Directives aimed at environmental compensation (Lipton et al 2008).[7] As described in Section 3.1, EA is divided into three typologies: Habitat Equivalency Analysis (HEA), Resource Equivalency Analysis (REA) and Value Equivalency analysis (VEA).

Flores and Thacher 2002 (p. 174) describe the welfare equality that must hold following compensation, where $V_i^0(.)$ is individual *i*'s indirect utility function prior to damage and compensation and $V_i^1(.)$ reflects the after scenario:

$$V_i^0(E,E^0,y_i) = V_i^1(E - L, E^0 + R, y_i) \qquad (1)$$

[6] The key assumption here is that individuals in society are adequately informed about how ecological loss affects his/her well-being. Given the extent of ecological research into the impacts of environmental loss on society and ecosystems, there is reason to believe that it is difficult, if not impossible, for a typical individual to be adequately informed.

[7] In addition to the ELD, see also Habitat and Wild Birds and Environmental Impact Assessment Directives.

Utility is assumed to be a function of the individual's net income, y_i, the value of the environmental services derived from the damaged (E) and restored resources (E^0) and the debit, L, which represents the lost value associated with the decline in E (I ignore the time dimension here, see Section 3.2.7). Under the VEA approach, E and E^0 need not be perfect substitutes, as is assumed under REA/HEA.

Equation (1) makes the assumption that the polluter pays (Polluter Pays Principle, PPP) and that the victim of environmental damage, whose utility is represented in (1), does not experience a net change in income from the compensatory payment R. Paper III takes issues with this "cost-free compensation" assumption and suggests that the scale of R should also be a function of the individual's opportunity costs, c_i of paying for the compensation:

$$V_i^0(E, E^0, y_i) = V_i^1(E - L, E^0 + R_i^*, y_i - c_i) \quad (2)$$

A number of economic ideas underlie the concept of environmental compensation and are implicit in this study, which assumes:

- a 'welfarism' paradigm, which assumes that all changes that affect human well-being be evaluated in terms of utility, or some type of value information (Berrens 2001). Welfarism is challenged most frequently when there is considerable uncertainty in measuring the effect of some change on utility, which may be the case with the assessment of environmental resources.
- the legal requirements for compensation are motivated by human welfare concerns. The implication is that the *direct* impact of interest is on society's welfare, which itself is affected by ecological change -- a point which can be lost when using non-monetary metrics as in HEA/REA (this fact has motivated the title for this thesis, see Paper II).
- an external market failure is present which requires environmental compensation regulations (in a perfectly competitive market, government intervention would be superfluous). That is, producers fail to consider the full environmental costs of production, leading to overproduction and social welfare losses. This assumption is key to understanding the critique put forth in Paper III.
- a public goods market failure is present due to the non-divisible and non-excludable nature of the compensation mechanism (see Paper III). Thus, distributional impacts are unavoidable: there will

be 'winners' and losers' in a heterogeneous society following a compensatory project.

- society is willing to trade-off (substitute) a restored resource for a damaged resource and that these social preferences lie behind the sought-after equivalency between lost and gained resources. In the case of threatened or rare habitats substitutability may not be a reasonable assumption, in which case economics has less to contribute to damage assessment.[8]
- compensation costs society money but returns benefits in terms of biodiversity and ecosystem service improvements (just as pollution abatement does for air quality). This type of trade-off is generally not acknowledged in EA (Paper III)
- the compensatory scaling methods discussed here are only applicable in the case of marginal changes to a damaged and restored resource (i.e., cases of species extinction or contamination of the 'last few acres of wetland' in a region are not suitable for this scaling approach).
- our framework is a deterministic approach, which does not explicitly take into account uncertainty as it relates to, for example, individual preferences or ecological outcomes. For example, rather that explicitly accounting for future uncertainty as in a stochastic approach, EA generally considers uncertainty *ex post* through a sensitivity analysis of key parameters such as the discount rate, extent of ecological loss, years until ecological recovery, etc.

The remaining part of this study is organized as follows. Section 2 summarizes the purpose and objective of the study. Section 3 describes the welfare economic issues that arise when measuring resource-based compensation and also introduces EA as a scaling method. Section 4 summarizes my contributions from papers I, II, and III.

[8] When compensation is *ex post* the damage has already occurred and compensation is legally binding. In this case, the legal requirements may guide scaling to a greater extent than social preferences.

2 Purpose and Objective

The purpose of this thesis is to analyze the social welfare implications of providing resource-based environmental compensation for environmental injuries. The thesis focuses heavily on the Equivalency Analysis (EA) scaling approach. Specifically, I aim to:

- Study the welfare implications of using a non-monetary metric (e.g., acres of habitat, number of birds, etc) as in Habitat Equivalency Analysis (HEA) and Resource Equivalency Analysis (REA). See Licentiate thesis (see Cole 2010. ISBN 978-91-86197-78-0)
- Develop an REA application in an interdisciplinary setting together with ecologists to address a contemporary environmental loss: wind power development and bird collisions (Paper I).
- Communicate the economic framework for compensation to ecologists in order to broaden the debate on environmental compensation. The goal is to encourage more interdisciplinary cooperation by highlighting an issue that is frequently mischaracterized by ecologists: that our goal is to determine how environmental change affects human well-being (Paper II).
- Criticize EA's conventional focus on equity for the victims of environmental damage by suggesting an alternative scaling criterion based on efficiency. The goal is to focus more broadly on social welfare and to consider how best to assess the environmental trade-offs inherent in environmental compensation (Paper III).

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3 Economics of Compensation

Welfare economics studies the impact on individuals and society of policies, economic activity, or other changes that may affect human welfare. The tools of welfare economics can help us to evaluate a compensatory payment to offset an individual's utility loss and to discuss the implications of aggregating the impacts of that payment.

Historically, environmental compensation has been driven by *ex post* legal obligations to clean up and repair for de facto environmental injuries. These *ex post* scenarios in the US are driven primarily by the Natural Resource Damage Assessment (NRDA) regulations, while in the EU they are driven by the Environmental Liability Directive (Directive 35/2004; Brans 2006). Under both EU and US statutes the key component of the compensatory assessment is the *interim loss* (Figure 1), which the compensatory measure is supposed to offset. The interim loss is the loss of human well-being that remains after clean-up activities and damage-reducing measures have been undertaken, or financial compensation for market losses has been paid.

From a welfare economics perspective the value of the victim's interim loss is the monetary compensation needed to restore the individual to the pre-spill level of utility (Dunford et al. 2004). However, the US and EU statutes preclude monetary payment of compensation to victims, requiring instead a resource-based compensation project (e.g., a public good). Given this restriction on the compensation mechanism, damage assessment has evolved in the US and EU to focus on the direct scaling of resources required to make the public whole rather than on the monetary assessment of damages for the purpose of compensating on the individual level (Flores and Thacher 2002).

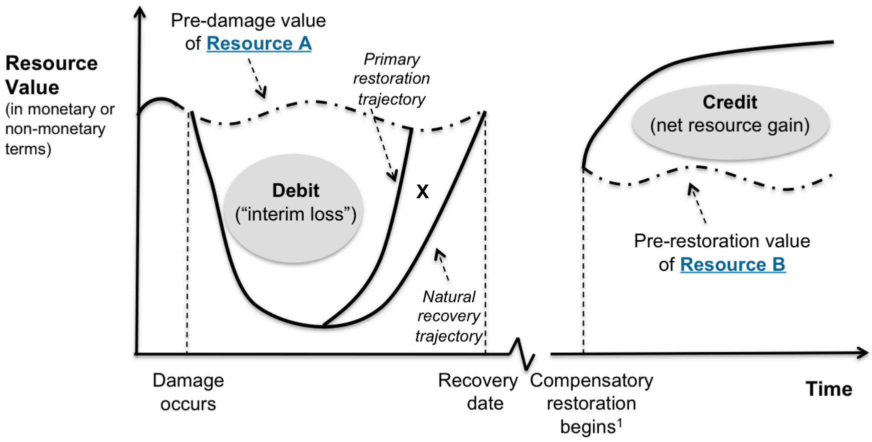
3.1 Equivalency Analysis (EA)

The EA method has been developed around the concept of the interim loss of resources to the victim. EA aims for 'equivalence' over time and space between the present value of the interim loss (debit) and present value of the subsequent resource gain (credit), as in Figure 1. The interim loss is a function of, among other things, primary restoration, which is scaled using biological criteria aimed at improving the recovery rate of the damaged resource. It indirectly affects social welfare because it reduces the size of the interim loss and, thus, the compensatory payment. In contrast, natural recovery leads to an increase in the interim loss (all else equal) by the area X in Figure 1 (i.e., X is the benefit of primary remediation).

The debit and credit can occur in different locations and at different points in time, where the later leads to discounting resource (Section 3.2.7). The value of the debit/credit (Y axis) is measured relative to the pre-damage or pre-restoration level of the resource and can be captured in monetary or non-monetary terms (Section 3.2.2), i.e., equivalency may proceed under two assumptions:

- A Value Equivalency Analysis (VEA) measures the environmental loss and gain in terms of its affect on an individual's utility. This utility change could be measured using a monetary measure (Parson and Kang 2010) or could be assessed using the quantity of a resource that is gained and lost (Breffle and Rowe 2002). In the former case, a monetary sum is attached to the loss and gain using economic valuation techniques and compensation is scaled based on this information. Note further that this describes a value-to-value variant of VEA, but a cost-to-value approach, which is frequently used in the cases of recreational losses, is to scale the compensatory project such that its cost is set equal to the lost value in monetary terms.
- An REA or HEA measures the environmental loss and gain in social welfare using a non-monetary (ecological) metric such as acres of habitat or number of species. Rather than assigning a monetary sum to the value of the public's loss and gain, the non-monetary metric is a proxy for the change in human welfare. These approaches are sometimes referred to "resource-to-resource" or "service-to-service" scaling.

Figure 1. The debit and credit in Equivalency Analysis (EA) scaling



[1] In theory, the credit may begin accruing *before*, *during*, or *after* the interim loss and may be *on* or *offsite*. Figure 1 illustrates the *after* and *on-site* case. Adopted from NOAA (1995)

3.2 Measuring resource-based compensation

A number of welfare economic issues arise in an interdisciplinary damage assessment aimed at scaling a resource-based compensation payment. Each of the subsections that follow describe how these issues arise and identify when EA may deviate from the welfare-theoretic approach.

- (Section 3.2.1) A measure of well-being
- (Section 3.2.2) A currency for valuing trades
- (Section 3.2.3) Sufficient scale of compensation
- (Section 3.2.4) The compensation mechanism
- (Section 3.2.5) Aggregating individual preferences
- (Section 3.2.6) Who is paying compensation & who is the victim?
- (Section 3.2.7) Accounting for time: discounting

3.2.1 A measure of well-being

The basic assumption is that individuals choose to consume goods (private and public) that maximize their utility, an unobservable measure of well-being. The question is how to compensate an individual when he/she cannot consume an environmental good due to environmental damage.[9]

The indifference curve in Figure 2 measures individual preferences between an amount of private (X) and public goods (Q), in particular the combinations of X and Q for which an individual is indifferent i.e., (Q_1, X_1) provides the same utility as (Q_2, X_2) but he is better off with (Q_3,X_3).[10] A key point is that he can easily substitute one for the other and still maintain the same level of well-being or utility represented by U_1 or U_2. This implies that he can be compensated for the loss of one good by the provision of an alternative good, where the relevant trade-off in this case is between a damaged and restored, re-habilitated, or replaced resource.

Moving northeast in Figure 2 is preferred as the individual receives more of both, but such movements are constrained by budgets or other restrictions. In other words, the individual cannot "get something for nothing" and must trade less of one thing in order to receive more of another, an underlying assumption to the critique in Paper III.

However simple the assumptions of substitutability and trade-offs, these concepts underlie the majority of economic models that estimate individual choice (Freeman III 2003a) and are particularly important in the context of resource compensation.

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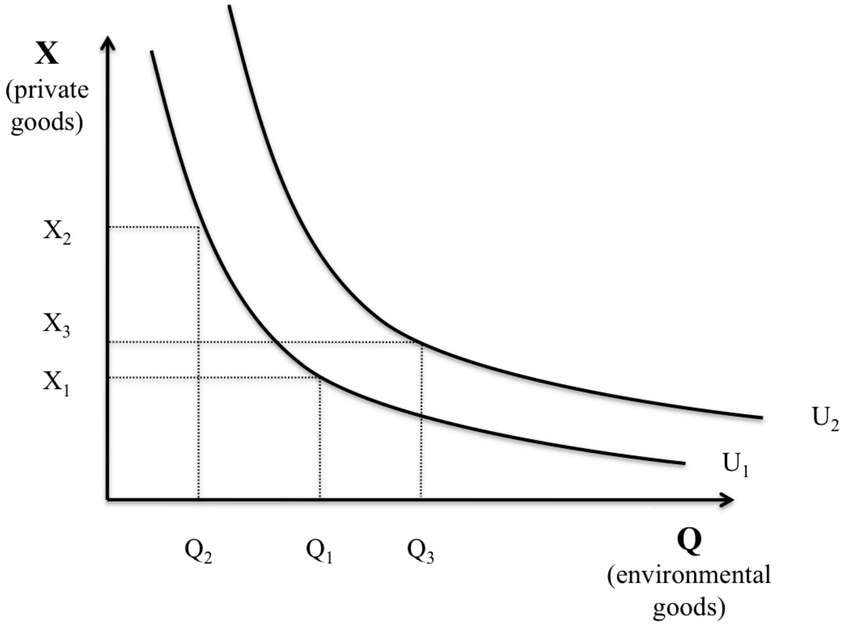
[9] Environmental compensation focuses on welfare losses from environmental injury, exclusive of profit loss (e.g., producer surplus). Loss of profits to businesses that rely on a resource or service (e.g., fishing tourism impacted by a chemical spill) is addressed through alternative legal channels (e.g., tort law).

[10] As drawn the curves approach each axis without touching, indicating that substitution is always possible. If U_2 became strictly vertical at Q_2 it would indicate that the individual is no longer willing to trade less Q for more X, as in perhaps an endangered species. This implies that both goods are assumed "essential" which implies that this individual cannot be compensated for a complete loss of either resource.

Figure 2 Individual indifference curves



3.2.2 A currency for valuing trades

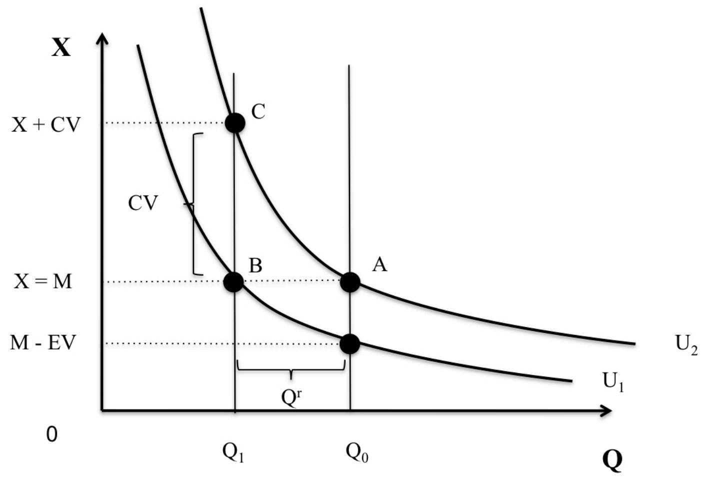
Because individuals' utility changes are not observable, an indirect proxy to measure welfare is required. At least two measures are possible: a monetary and non-monetary currency (numeraire) for valuing trades between damaged and restored resources.

A frequently used currency in this context is money.[11] That is, one could ask the individual suffering the loss Q_0 -> Q_1 in Figure 3, how much he would demand to return to the pre-damaged level of well-being (represented by U_2). This is called the compensating variation, CV (see Section 3.2.3) CV is the vertical distance on the Y axis and is the 'good' provided in lieu of the desired good (Q). CV could be measured in terms of the private good, X, or money, which can purchase the

[11] Of course alternative currencies or numeraires could be used, but money is convenient because it is divisible.

private good. A VEA may use a monetary measure currency, though it need not.

Figure 3 Compensating an individual for a reduction in the non-market public environmental good, Q



EA is motivated by the notion that money measures of utility changes are objectionable or too difficult to estimate (Unsworth and Bishop 1994). Thus an alternative currency for the purpose of paying compensation is to use a non-monetary or ecological welfare metric that is common to both the debit and credit (e.g., acres of habitat, number of birds). This necessarily involves a number of strong assumptions (Dunford et al 2004). First, that the ecological metric fully captures the complex changes occurring in a damaged and restored ecosystem.[12] Second, that we can proxy welfare with changes in an ecological metric. Relying directly on this ecological change (as in HEA/REA) rather than filtering the effect of this change through an indifference curve that reflects an individual's preferences runs the risk of wrongly assuming a linear approximation over an entire interval (e.g. restoration project). This may be a problem when

[12] Peterson and Lipcius (2003) identify the progress required to improve the use of ecological metrics for scaling restoration.

evaluating non-marginal projects.[13] Third, the approach assumes constant real value of resources over time (Unsworth and Bishop 1994). This assumption may not hold under various assumptions e.g., if the restored resource becomes more or less scarce over time.

Thus, welfare economics suggests that the currency with which compensation may be traded or valued could be based on observable monetary or non-monetary measures of utility changes.

3.2.3 Sufficient scale of compensation

Figure 3 illustrates the sufficient quantity (scale) of the compensatory payment, using both a monetary and non-monetary measure of utility. The payment assumes that the initial utility level is constant (U_2) and associated with the status quo - the right to an uncontaminated environment (Q_0). The scaled payment must be sufficient for the individual to be indifferent between the initial clean environment and a contaminated one, given a reduction in Q from point A to point B (Q_0 -->Q_1).

In the case of compensating an individual for a loss -- where the point of comparison is the pre-loss level of well-being -- a willingness to accept compensation, i.e., Compensating Variation (CV) is the correct welfare measure (Freeman 2003). CV is sufficient to offset the interim loss in Figure 1 and thus represents the correct magnitude of compensatory restoration[14] as described in Section 3.2.3 CV can be estimated using economic valuation, where individuals are asked to state their willingness to accept compensation. Using the definitions from equation (1), it can be represented as (Unsworth and Bishop 1994; Flores and Thacher 2002; Roach and Wade 2006):

$$u_I^0(E,E^0,y_i) = u_i^1(E - L, E^0, y_i + CV_i) \qquad (2)$$

The individual is fully compensated by a payment of CV_i

[13] If a project is non-marginal (i.e., covering a significantly large interval), then a linear approximation of preferences is particularly questionable. Such projects can still be assessed based on social preferences, but generally require a more sophisticated model to determine how preferences change across the interval. A specific example of this is Breffle and Rowe (2002) who ask respondents in a choice experiment to value both the loss and gain as a whole.

[14] This assumes the damaged environment is returned to baseline. If it does not (i.e., long term damage), complementary restoration would be needed in addition to compensatory restoration.

The payment can also be based on the non-monetary measure of utility along the X axis, but sufficient compensation is necessarily greater than Q^r shown in Figure 3, which depicts a scenario where the damaged environment is immediately "given back" to the individual. In reality the debit and credit accrue over long time periods and thus Q^r is insufficient because it does not account for full interim loss.

The sufficient scale of compensation for individual *i*, R_i, can be estimated by asking individuals to state the amount of resources (a non-monetary metric) they would require as compensation to ensure they remain on their original utility level (Examples include Breffle and Rowe 2002; Molowny-Horas et al 2008). Assuming V_0 is the indirect utility prior to damage and V_1 is post-damage, it can be represented as:

$$V_0(E,E^0,y_i) = u_1(E- L, E^0 + R_i, y_i) \quad (3)$$

Therefore, R_i is also an appropriate measure of compensatory restoration for environmental damage. Note, however, that R_i cannot be divided and exclusively provided to each individual which has implications for aggregation (see Sections 3.2.5 and 3.2.6)

Table 2 summarizes the differences in both indirect utility measures for compensation of environmental loss.

Table 2 Comparison of compensating welfare measures for environmental loss

Compensating measure	Basis for well-being measurement	Method for obtaining measure	Stated Preference scenario
CV - (Y axis in Figure 5) [see formula (1)]	utility	Stated preference survey with monetary metric	How much compensation would you be willing to accept in terms of *money* to return to the original (pre-damage) utility level?
$R > Q^r$ (X axis in Figure 5)	utility	Stated preference survey with monetary metric	How much compensation would you be willing to accept in terms of *resources* to return to the original (pre-damage) utility level?[a]

[a] The HEA/REA approach obviates the need for a stated preference survey and instead assumes that society is willing to trade-off the value of a damaged resource with a restored resource in proportion to change in the non-monetary metric.

3.2.4 The compensation mechanism

Although the individual welfare impacts of the compensatory payment may be valued using in money (CV) or non-monetary measures (R), the actual provision of compensation is restricted to a resource-based project, i.e., a public good. For example, the ELD notes that an interim loss " ... does not consist of financial compensation to members of the public" (ELD Annex II 1(d); see also Randall 1997).

In theory at least, alternative compensation mechanisms are possible, if individuals are willing to trade-off the consumption of one good for another. Lazaro-Touza and Atkinson (2009) conducted a survey to assess the willingness of individuals to trade-off environmental damage from an oil spill with three types of social improvements: (1) man-made capital infrastructure (roads), (2) social capital (schools, hospitals), and (3) natural capital (environmental compensation projects). They found that individuals preferred social capital to natural capital at an almost 2 to 1 ratio to compensate for oil damage (these compensatory alternatives also represent public goods). The authors suggest that this supports the speculations of Turner (2007) that money may not compensate for certain environmental losses.[15]

Welfare economics suggests that money is a convenient compensation mechanism because, in theory, it is divisible and can be provided in different amounts to different individuals to exactly compensate their loss. Flores and Thatcher (2002) argue that money is the only theoretically pure compensation mechanism for environmental damage.[16] For example, following contamination of a popular sports fishing lake, a fishermen could be provided monetary compensation to offset his/her presumably larger utility loss, as compared to a non-fishermen. This is not the case when the compensation mechanism is a non-rival and non-exclusive public good because "... no one can be excluded from the benefits [of consumption] and additional consumers may use it at virtually zero marginal costs" (Johansson 1991, p. 63-64). The implication is that environmental compensation cannot compensate every individual, i.e., there will be winners (e.g., non-fishermen) and losers (fishermen). Unless

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[15] In theory we can always compensate individuals as long as their indifference curve intersects the appropriate axis/dimension. However, compensation (in any form) is impossible for the complete loss of an essential good, i.e., goods that never intersect the axis.

[16] Note this is essentially an academic point due to the legal restriction.

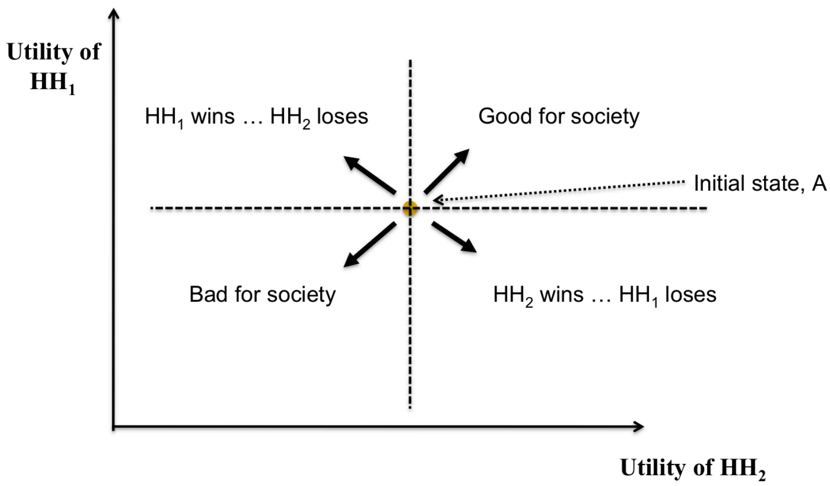
preferences are homogenous resource-based compensation can only be provided on the aggregate level (Jones and Pease 1997).

3.2.5 Aggregating individual preferences

Assessing social welfare requires a scaling up of the individual-level analysis. In general this requires a number of unavoidable value judgments such as the weight assigned to different people's well-being. In the case of a resource-based compensation mechanisms, aggregation is further complicated by the inevitable winners and losers in society. The question is how to determine the net effect on social welfare of these individual winners and losers?

The goal is determine which quadrant society reaches in Figure 4, following a damage and subsequent compensation project. It illustrates how a 'social planner' might consider the trade-off in utility between two households (HH_1 and HH_2) when deciding whether to proceed with a e.g., a compensation project, given an initial state A.

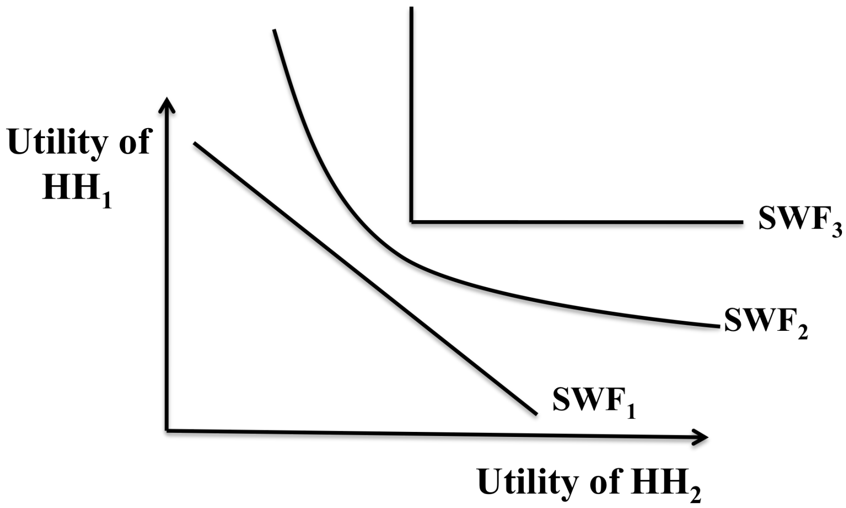
Figure 4 Alternative social states, or outcomes, from a proposed policy action (based on Johansson (1991), Figure 2.1).



The Pareto principle suggests that projects should be undertaken as long as nobody is made worse off (i.e., only northeast-moving projects). But such a criteria cannot handle cases of winners and losers (northwest and southeast). An alternative is the compensation criteria based on Kaldor-Hicks, which suggests that a project should be undertaken so long as the winners can hypothetically 'compensate' the losers and everybody is still better off. 'Compensate' in this case refers to the redistribution of the (presumably inequitable) allocation of income. It is a less than ideal criteria because it makes an *a priori* assumption that the utility of each individual in society is valued evenly at the margin (i.e., it cannot compare how much the losers 'lose' and how much the winners 'win,' in order to decide whether a project has net social benefits). This is due primarily to the fact that the compensation principle assumes that welfare is optimal, i.e., that the social marginal value of an additional dollar is independent of the individual.

A more ideal, though not so practical, criterion is to rely on a Social Welfare Function (SWF) which provides a complete and consistent ranking of social projects. The shape of the curves in Figure 5 implicitly evaluates the trade-off in utility between HH_1 and HH_2. For example, if a restoration project stands to benefit HH_1 to a greater extent than HH_2, the social planner could simply consult the relevant SWF, which identifies how society weights the utility of individual households, and then decide whether the project results in net social benefits or not. Inevitably, this requires normative input from society's decision-makers. The conventional approach is to avoid a discussion of weights and relying on the assumption inherent in Kaldor-Hicks: each and every person's utility is valued equally, as shown by SWF_1 (even the decision that each household's utility change should be weighted equally involves an ethical judgment).

Figure 5 Alternative Social Welfare Functions (SWF)



SWF_1 represents an egalitarian or utilitarian shape, which is most commonly assumed (though not necessary) form in practical application such as a CBA and has a slope of 1. SWF_2 represents a progressive form, which weights the utility change of the "utility poor" higher than the utility change of the "utility rich." Finally, SWF_3 represents a Rawlsian form which argues that the welfare of society is a function only of the worst off households (i.e., society gains nothing from projects that increase the utility of the well-off).

Figure 6 illustrates the EA version of Figure 2, but on a societal level. This diagram demonstrates the social trade-off implicit in environmental compensation, as scaled by EA: the X-axis represents the damaged environmental resource (Q_2) and the Y-axis represents the restored environmental resource (Q_1). Equivalency analysis assumes that society *as a whole* is willing to trade-off a damaged environment with a restored environment which necessarily implies winners and losers. Figure 6 assumes that preferences have been aggregated based on some criteria and ethical judgment, which allowed for a social trade-off between resources to be made. Figure 5 represents a discussion of how to make that aggregation in the first place.

Figure 6 Social indifference curves underlying Equivalency Analysis (EA)

Thus, positive economic analysis precludes guidance on how to determine the net welfare effect of compensation. This is true even if the compensation mechanism is money, but it is particularly challenging when a public good is involved because compensation can only be provided on a societal (not individual) level. In short, social welfare involves ethical judgments, either by establishing weights for the value of individuals' utility changes (as in a social welfare function[17]), or by implicitly assuming that individuals' utilities are equally valued, thus allowing for the application of the Kaldor-Hicks compensation principle.

3.2.6 Who is paying compensation & who is the victim?

Note that equation (1) implicitly assumes that the polluter pays and individual *i's* utility is in no way affected by the compensation payment. If this is the case, then VEA represents a defensible and welfare-theoretic approach to scaling resource-based payments (as noted in Section 3.3 HEA/REA has other short comings).

But this assumption may not hold under various scenarios such as (1) individual *i* owns capital invested in the polluting firm; (2)

[17] Kanninen and Kriström (1993) showed how the results of a CBA may change depending upon the slope of the assumed social welfare function.

individual *i* is a taxpayer in a scenario where the government pays for part of the compensation or clean up costs; (3) individual *i* is a consumer of a product produced by a monopolistic polluter, i.e., the firm is not a price taker and therefore may exert influence on prices the consumer pays in response to the government's compensatory requirement. In short, equation (1) does not account for the opportunity cost of compensating environmental damage, which may be so high that the individual's utility may fall, thus invalidating the equality. Even if none of the above scenarios hold for a specific individual, the compensatory damages in monetary terms collected from the polluter on the public's behalf represents scarce societal resources which, it could be argued, should be subject to a test of social efficiency.

This raises the question of whether the general EA framework in (1) is satisfactory from a social welfare perspective. I examine this assertion in Paper III.

3.2.7 Accounting for time: discounting

In compensating individuals for private loss the underlying assumption is that the compensation mechanism (usually money) is provided immediately. This is not the case with environmental compensation because of the dynamic nature of debits and credits.

Time affects compensatory scaling in two ways. First, the debit and credit may occur at different times ("time discrepancy"). Most frequently (but not always) the damage occurs relatively close to the present while the compensation gains occur further into the future, as shown in Figure 1. The main reason is that loss and gain is dynamic (i.e., a planted tree or an enhanced wetland provides ecosystem services gradually over time. Debits also follow a gradual pattern of decreasing loss (recovery) over time. Second, debits and/or credits may occur extremely far into the future, which demands contemplation about how the current generation (the decision-makers) should weigh the (uncertain) impacts on future generations, when these generations are not able to express their preferences today.[18] Thus, a discount

[18] There are several environmental parallels to this problem: biodiversity protection, endangered species protection, climate change impacts, storage of radioactive waste, thinning of the ozone layer, persistent groundwater pollution, minerals depletion, etc. See Weitzman (1998). A further list of references can be found in Nordhaus (1994) and Layton and Levine (2003).

factor is used to adjust the value of impacts occurring at different times so that they are comparable.

As with CBA, the weighting system used in EA is based upon an assumption that society exhibits a positive time preference, thus reducing the value of debits/credits occurring in the future (discounted) and increasing value of debits occurring in the past (compounded). Resource flows are considered analogous to financial annuities in this respect, i.e., individual are presumed impatient when it comes to (direct or indirect) resource consumption (NOAA 1999; Cole and Kriström 2008).

In the licentiate counterpart to this dissertation I explore the assumptions and consequences of discounting resource flows in greater detail (Cole 2010). I conclude that the basis for using a discount factor to weight the value of impacts according to "present value" is well-established, although the specific value of this weight attracts disagreement due to the extraordinary effect the discount rate can have on the conclusion of long-term damage assessments. By not using a discount factor, we are implicitly assuming that society is infinitely patient and can wait for restoration to occur. Plenty of evidence exists to contradict this assumption. From a practical matter, a discount rate also helps when calculating impacts from perpetual damage.

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4 My contribution

Below I summarize the key economic contributions from my three papers and how they fit together in the social welfare assessment of resource-based environmental compensation.

4.1 Paper I - "Scaling electrocution prevention measures..."

The first paper in my dissertation was developed in 2009 and it provides several contributions.

First, I apply the REA method to the case of past and projected environmental injury from a wind turbines. Although frequently applied to oil spill losses ex post, it has never been applied to wind power compensation, which is generally characterized by political negotiation or convenient projects rather than linking welfare losses to welfare gains. In this particular application, the focus was on raptor collisions with turbine blades, but the environmental impacts of wind power in general are expected to become increasingly relevant in the future due to the strong demand for CO_2-free energy. The framework put forth in this paper provides authorities, environmental groups, and the wind power industry with an interdisciplinary approach to scaling compensation measures as suggested in the Environmental Impact Assessment (EIA) hierarchy: "avoid --> minimize --> compensate

Second, I suggest an innovative compensatory project to compensate for bird losses: retrofitting of power lines to reduce bird electrocution. This type of compensation project has not previously been suggested for bird compensation and received positive feedback from biologists at three international conferences over two years. To support the argument for this approach I suggest a practical policy whereby wind power companies address electrocution mortality at existing power lines, while utility companies are responsible for preventing electrocution at all new power lines. The results of my study provide impetus for improving electrocution probability models to ensure the compensation measure is cost effective.

Third, I worked in an interdisciplinary setting with biologists in Norway to incorporate complex ecological information on the impact of the wind farm on birds and the potential ecological gains associated with power line retrofitting. This required a comprehensive understanding of the ecological population model and what it implies in terms of social welfare impacts.

Fourth, I advanced an existing methodological approach of using bird-years (BY) as a non-monetary metric in an EA. Specifically, I adapted the calculations BY losses to the case of a long-lived raptor species (white tailed eagle) and interpreted the welfare impacts. Further, I highlight a key limitation of EA which is that the method does not address the real environmental trade-offs of choosing to compensate at a particular site. Instead, it simple provides a scaling approach, *given* that compensation has already been deemed appropriate. Together with paper III I stress the fact that environmental trade-offs must be addressed in the *ex ante* setting in order to assess the social profitability of compensation as a policy approach.

4.2 Paper II - "Wind power compensation is not for the birds ..."

The motivation for Paper II came after a trip to Scotland to attend the Raptor Research Foundation annual meeting and ornithology conference. I applied too late to be able to present paper I, but decided to attend anyway in order to "float my idea" about electrocution prevention as a compensatory measure for turbine losses. It turned out to be a fateful trip.

The biologists I spoke to fully enforced my idea and enthusiastically pointed me toward researchers that were working with electrocution prevention issues who, in turn, were even more eager to support my idea as it provided a potential outlet for the results of their research.

I was introduced to several researchers and found myself explaining my idea repeatedly, which honed my ability to speak "economics" with ecologists. After a late night discussion at the bar with a couple of fellow PhD students in ecology about the anthropocentric basis of compensation, I decided that one of my own PhD contributions would be to improve the dialog between the disciplines. I set to work on an outline for the paper on the flight home.

The process of writing the paper was not only helpful to my own development as an environmental economist, but I would like to hope it was even fruitful for the ecologists that read several early drafts of the paper (I certainly benefitted through a better understanding of raptor population dynamics). During one of the several drafts where I was trying to explain to an ecological readership that compensation was for "us humans," I found just the way to express it: compensation is *not for the birds*.[19]

Thus, my contribution was nothing more than creating a dialog with ecologists. Admittedly, I did not discover any new economic theory or insight, but rather tried to communicate fundamental economic assumptions in a way that might be helpful to further collaboration. The main contribution was to clarify that the intended goal of environmental compensation is "no net loss of welfare" rather than biodiversity per se, although admittedly both goals lead to measurement challenges. I hope that this lays the foundation for future interdisciplinary work for me later in my career.

4.3 Paper III - "Equity over efficiency..."

The purpose of this paper is to consider the welfare implications of alternative methods for scaling environmental compensation. I critique the conventional Equivalency Analysis (EA) approach and suggest an alternative scaling approach based on cost-benefit analysis (CBA). A key finding is that the inescapable environmental trade-offs facing society in compensating environmental damage are ignored in the EA framework. The proposed CBA framework is more in line with governments' increasing -- but still limited -- use of environmental CBA to steer society's scarce resources to a variety of environmental challenges.

[19] Because the expression "for the birds" refers to something that is *objectionable or not worth doing*, the double meaning is relevant: environmental economics suggests that compensation *is* worthwhile and it's not (just) for the birds.

4.3.1 Critique of the EA scaling approach

To compensate for environmental damage the polluter incurs a number of costs including:

1) the cost of immediate clean up and response;
2) the cost of speeding resource recovery (i.e., returning the damaged resource to (or toward) the pre-damage baseline);
3) the diminution in value of the resources (interim loss), which is required if the resource does not quickly return to baseline; and
4) the reasonable costs of assessing the damages (e.g., data collection, assessment, monitoring, etc).

The conventional EA approach to scaling focuses exclusively on component 3 (equity for the victim of environmental injury) and assumes that the cost of carrying out an adequate compensatory project is incurred by the polluter. But if the victim owns part of the polluting firm the opportunity cost of compensating the damage (including all four components above) maybe be so high that the individual's utility may fall following compensation. In this case, I suggest that compensation implies a social opportunity cost -- rather than a private cost incurred by the polluter -- as society's scarce resources used for compensation could be used for an alternative compensation project (which costs less or provides greater benefits) or for private investment in the polluting firm (which may lead to social benefits such as increased producer surplus or increased employment). By ignoring the opportunity cost of compensating damage, EA assumes that all compensatory payments are welfare increasing.

4.3.2 The proposed CBA scaling approach

An alternative to the equity criterion is to consider the efficiency of carrying out a compensatory project. A CBA-scaled compensatory payment compares the total benefit of the project (what an individual is willing to pay to obtain it) to the project's opportunity costs (what an individual is willing to give up). This proposed scaling approach is analogous to determining an optimal level of pollution in the sense that the optimal compensatory payment may be zero, positive, or negative (i.e., additional damage should be allowed). An *optimal* compensatory payment R* assumes that society faces a trade-off between environmental protection and economic production, just as pollution abatement assumes a trade off between clean air and production.

4.3.3 Implications of the analysis

The paper identifies a number of implications of the two scaling approaches.

- The optimal compensatory payment scaled by CBA acknowledges environmental trade-offs in scaling compensation. Whereas regulatory intervention for air and water pollution externalities are generally motivated by an acknowledged trade-off between economic growth and environmental protection, the dominant use of EA -- which aims to return to the baseline state of the world regardless of costs -- would seem to imply that policy makers need not consider such trade-offs in compensatory scaling. But this is counter-intuitive from a scarcity perspective. CBA scaling acknowledges society's scarce resources and compares the marginal costs to the marginal benefits of a compensatory payment.
- EA was developed as a tool to implement regulations that were motivated by the Polluter Pays Principle (EC 2000). Thus, EA is based on an *a priori* assumption that public users of the damaged resource own the resource and the polluter must pay. In other words, EA seems to imply a particular social welfare function, which assigns a lower weight to the polluter's utility (which decreases from incurring the compensatory cost) relative to the pollutees' utility (which increases from receiving the compensatory project). These types of implicit weights are typically absent in the conventional "efficiency-driven" CBA approach where the welfare of those who own the polluting firm is no less important than the welfare of those who suffer from its damaging activity.
- EA assumes that the marginal benefit to an individual of an additional unit of compensation is constant and increasing. Thus, all else equal, larger environmental injuries require larger compensatory payments. CBA assumes that the marginal benefit of additional units of compensation declines as the supply of the

restored resource increases. This leads to the finding that CBA scaling may recommend a larger compensatory payment than EA scaling if the restored resource is an undersupplied public good, which is likely given that environmental goods tend to be characterized by non-exclusivity and non-rivalry.

- The paper suggests that credibility may lie behind policy makers' choice of the equity-focused EA method at the expense of efficiency. The mechanism for ensuring efficiency is price determined by supply and demand in a competitive market. Without markets it is difficult to measure a resource's opportunity costs, and thus 'efficient' resource allocations. Thus equity (EA) may be preferred to efficiency (CBA) because policy makers do not believe that non-market ecosystem services can be priced efficiently, leading them to stress the adequacy of the transfer from polluter to victim as the standard for measuring the success of a resource-based compensatory payment.
- A practical implication of the analysis for policy makers is that CBA scaling may be a reasonable complement to EA scaling. EA could provide a starting point for damage assessment, but CBA scaling could help highlight the inevitable trade-offs in order to aim for a more *socially* optimal compensatory outcome than the one suggested by the victim-focused EA approach.

4.3.4 Conclusion and contributions

There are strong economic arguments for protecting -- and compensating for the loss of -- ecosystem services upon which human welfare depends. There are also strong equity arguments for compensating individuals that are harmed by environmental damage. But protecting and enhancing ecosystem services requires that society spend time and resources that are necessarily unavailable for other purposes, which may also improve welfare.

The key contributions from this paper include the following. First, several papers have analyzed EA from an *equity* point of view (have victims been properly compensated). My analysis differs in that it focuses on social *efficiency*. An efficiency critique leads to the conclusion that the polluters' expenditures may represent a social opportunity cost.

Second, I suggest a new approach to scaling based on CBA, which considers the trade-off between economic growth and environmental protection. Previous literature has not identified this trade-offs, assuming instead that all compensation is welfare increasing.

Third, I discuss implications of the EA method not previously identified in the literature. For example, EA implies a particular shape for the social welfare function, which favors victims over polluters. Further, I suggest that policy makers' focus on the equity-focused EA scaling approach at the expense of efficiency may be due to a credibility problem: the lack of a credible approach for pricing resources may have led instead to a focus on the adequacy of the transfer from polluter to victim as the standard for measuring the success of a resource-based compensatory payment.

4.4 Suggestions for future research

The findings in the three papers suggest a number of potentially fruitful lines of future research.

- The legal requirements for *ex post* compensation have stimulated an economics literature to assess welfare impacts. The increasing demand for *ex ante* compensation (e.g., biodiversity offsets) requires additional economic input because the setting in which these assessments are conducted are different from the *ex post* scenarios. For example, it is difficult to determine when compensation is required under the "avoid-minimize-compensate" hierarchy as there is little guidance on how much avoidance/minimization is enough and when the compensation threshold has been reached (see Paper II). Thus we need more information on what society is willing to trade when it comes to resource loss (e.g., biodiversity and ecosystem services) and infrastructure development (e.g., wind power, railroads, etc). This information will help improve the compensatory scaling process.
- The ecosystem service approach to valuation - where ecological production functions identify quantity of ecosystem services that benefit mankind -- may prove to be useful in a compensatory context. A recent report in the US (NRC 2011) suggests that this approach has advantages over the HEA/REA approach when it

comes to compensating for non marginal environmental damages (e.g., 2010 Gulf oil spill). For example, it suggests broadening the definition of "services" in HEA to include ecosystem service values for humans, rather than assuming that habitat services are proportional to human welfare losses. Future research should consider how this information could be used to improve the flexibility of identifying compensation measures while maintaining the resource-based restriction on the compensatory mechanism.

- Given the likely continued reliance on the simplified HEA/REA approach, research should focus on the conditions for which ecological metrics may represent reasonable proxies for welfare. While HEA/REA avoids the difficulties of informing the public about the potential welfare consequences of ecological change, it places a significant responsibility on the interdisciplinary team conducting the compensation assessment. Future research could identify how and when this approach provides satisfactory results for society as a whole.
- The ecological field needs to contribute with specific quantifiable and verifiable compensatory projects that address species and habitat loss. Further, we need to close the knowledge gap in assessing the success of compensation projects. This gap will become a significant problem as compensatory requirements increase. Our restoration technology is fairly young. Can our ability to repair damaged ecosystems improve in the future and, if so, what does this imply about possibilities for postponing compensation and favoring development today?

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